THE BOYS' BOOK OF ELECTRICITY

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By CHARLES RAMSEY CLARKE and SIDNEY AYLMER SMALL

Illustrated by the Authors and Charles E. Cartwright

How Electricity is Made and Delivered.

THE BOYS' BOOK OF ELECTRICITY

A SIMPLE EXPLANATION OF THE MODERN IDEAS ABOUT

ELECTRICITY

WITH MANY SIMPLE EXPERIMENTS

BY

SIDNEY AYLMER SMALL

PROFUSELY ILLUSTRATED BY THE AUTHOR AND CHARLES E. CARTWRIGHT

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PREFACE

In the last decade so many new facts have been discovered about electricity, such a great number of new ideas in the theory of electricity have been argued out to the point where scientists agree to accept them, that the old explanations may be dropped and new ones put in their place.

New books must therefore be written, and here is a book for you boys that uses the latest facts and theories, yet explains them in simple language.

Luckily, these new ideas make electricity much easier to understand, so that now you may learn *why* and *how* electrical things work.

I hope that you will have as much fun and profit in reading this book and doing the experiments as I have had pleasure in writing it.

SIDNEY AYLMER SMALL.

CONTENTS

CHAPTER I

INTRODUCTION

WHY THIS BOOK WAS WRITTEN
- The Broken Wire
- What is in a Lamp Cord
- The House Wiring
- Resistance or Rheostat
- Reading Electrical Books

THE BRIGHT IDEA OF A NEW BOOK
- Putting the Idea Over
- About Pictures and Diagrams
- Let's Go

YOUR LAB.
- The Tools You Need
- Joining Wires
- Sources of Current
- Dry Cells
- Storage Battery
- A Safety Device
- Using the House Current
- The Transformer
- The Reducer

THE REASONS FOR EXPERIMENTS
- Seeing is Believing
- A Help to Understanding

TRYING ANYTHING ONCE

HOOK-UPS

The Boys' Book of Electricity

CHAPTER I

INTRODUCTION

"What is the matter?" said Mr. Peter Elmer when he saw that Junior and Mrs. Elmer were in earnest conversation. "Oh, Peter," replied his wife, "the electric cord that goes to the transformer of Junior's electric train must be broken. There was a short circuit or something and Junior had to stop playing with the train."

"Mother, that is a rheostat, not a transformer, and that is a wire, not a cord," shouted Junior.

"I would not shout at my mother," said Mr. Elmer. "Also, are there not two wires in that cord?"

"Why, the man said we had a three-wire system in the house," cried Mrs. Elmer.

"Well," replied Junior's father, "what we need is some good book that explains in a simple way about electricity. Perhaps we can find out the difference between a transformer and a rheostat, and how long circuits such as from here to the power-house, can have short circuits."

The following evening at dinner Junior said that his Science teacher had explained a lot of things to him, but that when told all at once it was too much to remember.

"Never mind, Junior," said his father, "I have three good books on electricity in a package on the hall table.

After I have had my coffee we shall hunt up the explanations about electrical trains, wires, short circuits, and the electrical things about the house."

The hour of bedtime for Junior found a not fully satisfied family. The verdict was that just exactly the book they wanted for Junior was not there. "Probably there ain't no such book," joked Dad.

It was then that Junior made the suggestion. "Why not get my Uncle Sidney to write an electrical book for me? I always understand things when he explains them to me."

"Fine," answered his father, "Your Uncle Sidney has been teaching electricity for twenty-five years to prep school boys and he has also taught men in a big university. He is the fellow to write a book for you and other boys. We shall ask him. Let us do it now. Get him on the telephone and we shall try to make him say yes."

Thus the idea of this book had its birth, and, boys, here is the book. In it you will learn what electricity is, what it will do, and why it does these particular things. Your puzzles about amperes and volts, about why the electric locomotive reverses when you move a certain lever, why you can't run a train from an induction coil, nor silver-plate spoons with alternating current, all these and many more will be explained.

Many interesting experiments which will help you to understand electricity have been devised. These are fully described with all the details so that you can readily follow the instructions and easily do the experiments.

Whenever a picture or a diagram will make things clearer, one is there for you. Whenever I use a word that I think you will not understand, I shall either explain it right there or ask you to turn to the Appendix where you will find a list of words and their meanings. But all this talk isn't the book, so "Let's go."

Your Lab.—If you are to understand electricity, it will be a great help to do some experiments. An electrical lab. need not occupy much space, and yet if you have a lab. you will have all your tools and supplies in one place, and you can have each tool and kind of material in its own spot ready to lay your hand on it.

The Tools You Need.—Your tools should be of medium size and fitted to your hands. When you buy your tools, try the "feel" of them.

Pliers.—*Side-cutting pliers* are of first importance. They will cut wires, assist in skinning insulation from the ends of wires, and hold things. They are shown in Fig. 1A.

Long-jawed pliers are very useful for holding flat metal sheets. They grip flat things much better than the shorter jaws of other pliers. Illustrated in Fig. 1B.

Combination pliers.—An excellent tool that has a medium length of jaw. It has a wire cutter so placed as not to interfere with the use of the jaws for holding things. This tool is shown in Fig. 1C. With side-cutting pliers, if you hold anything firmly, the cutting edge is apt to dent the surface. The long-jawed pliers have no side cutter to do any damage while you are holding things, but they will not hold flat plates firmly, because like all ordinary pliers their jaws open in a V shape. The combination plier is often called a *parallel-jaw plier* for the jaws open and close, always parallel to each other. They will grip flat things very firmly.

Round-nosed pliers are used for bending sheet metal and wires; also for smoothing kinks out of wires. Fig. 1D.

All these pliers should be either the five-inch size or that size which fits your hand the best. Beware of big tools for they will not go into small corners.

Screw-Drivers.—There are many different shapes of screw-drivers; short, long, thin and fat-handled,

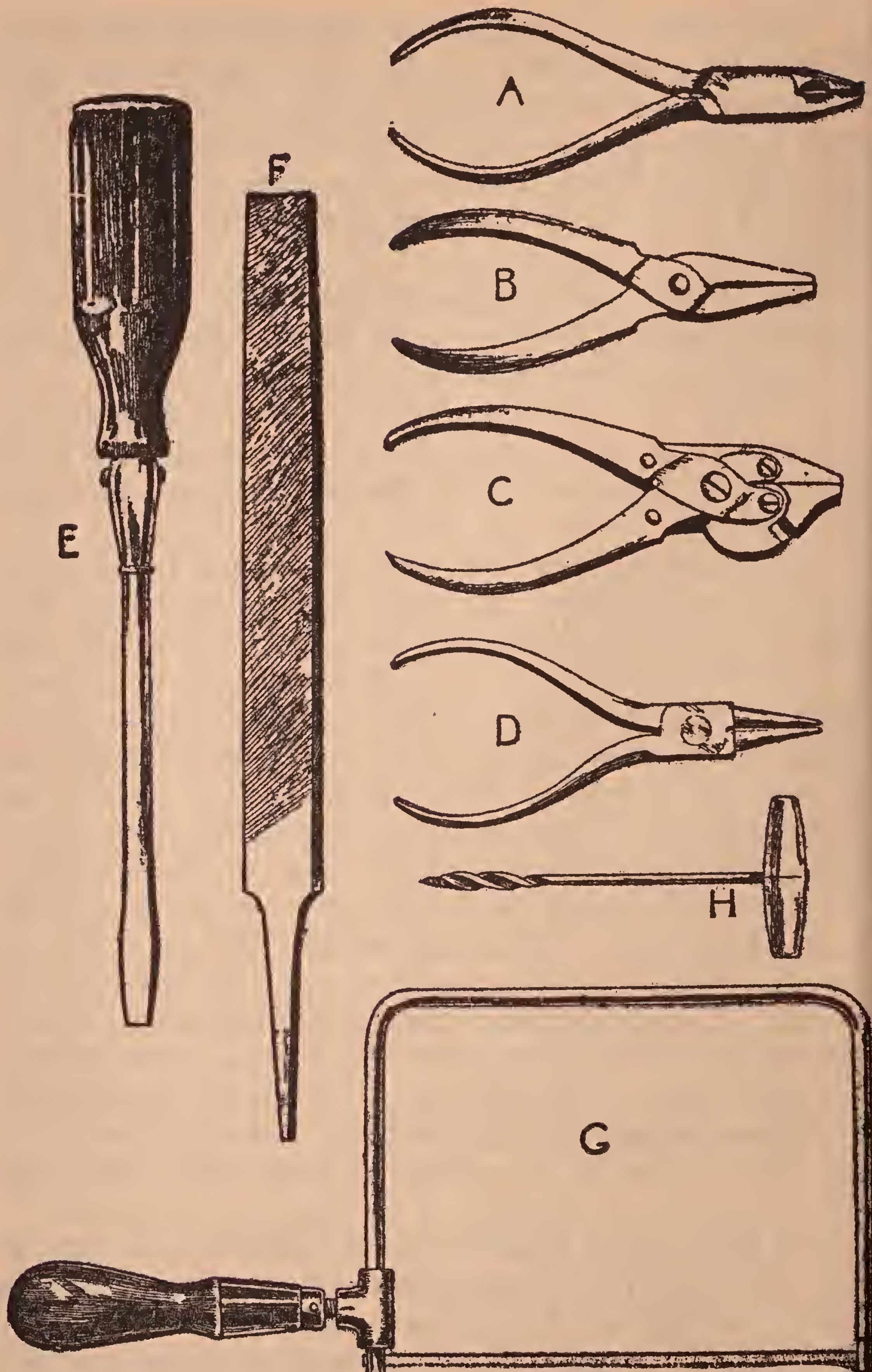

FIG. 1A. THE TOOLS YOU WILL NEED.

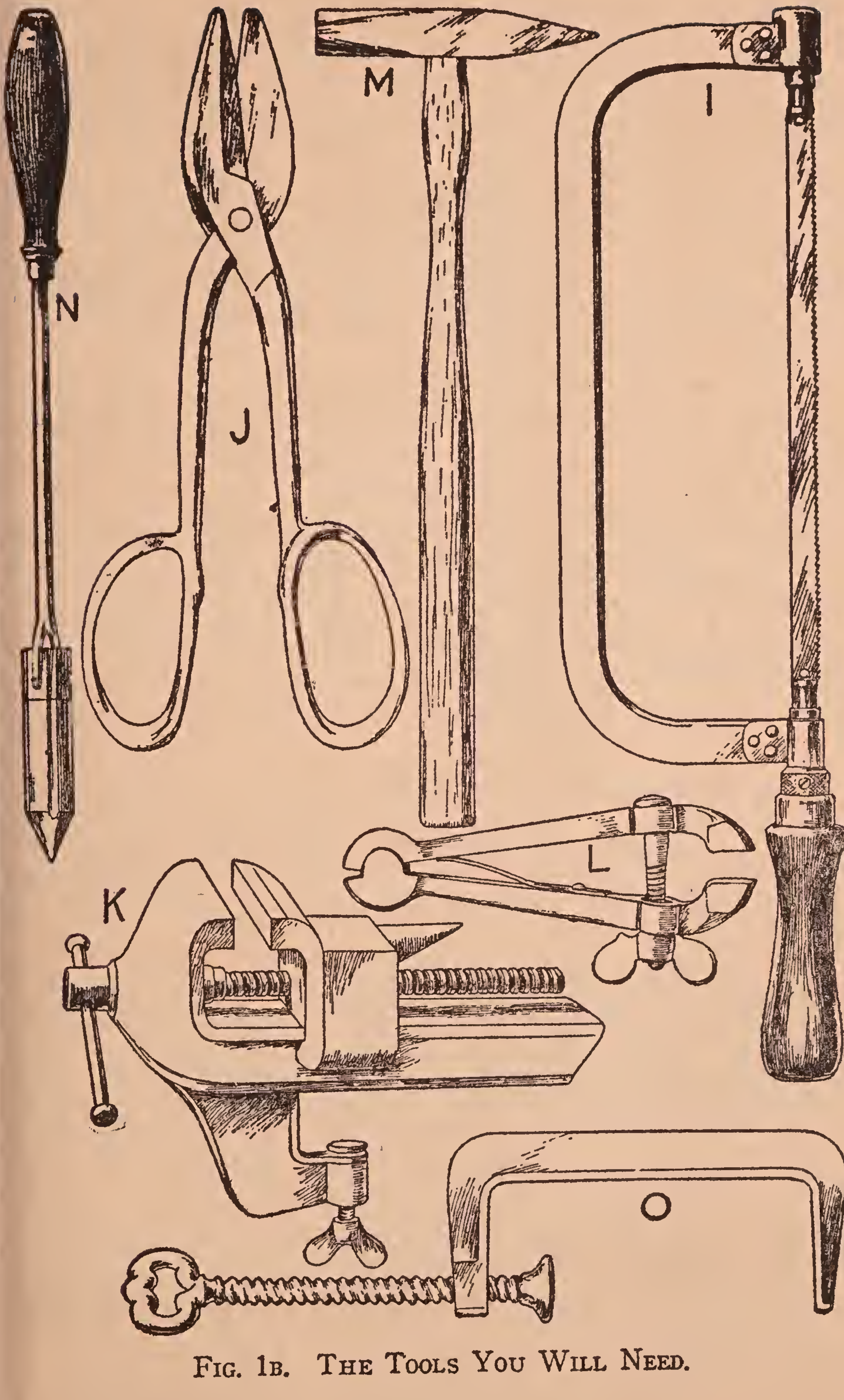

FIG. 1B. THE TOOLS YOU WILL NEED.

but at the business end they are all very much alike. There are three sizes of ends that fit all the ordinary-sized screws. Pick up a lot of screws, large and small, and an examination shows that there are but three sizes of slots on all the screws.

You will need one each of the two smaller sizes of screw-drivers. Let their lengths and the sizes of the handles suit your own taste in tools. One of the very small, slender screw-drivers will be very useful for getting into narrow places.

I do not like the automobile type, combination tools for lab. work. These tools are so apt to be suitable for the large-sized screws, bolts and nuts, but out of place for the work that you will do.

Files.—Small flat files about six inches long and with a surface called *mill* are needed to smooth off corners. The rat-tail or round file is used to smooth the inside surface of holes. You do not need tri-angular files. For a very coarse file use the broken hack-saw blade that you will soon have after starting work.

For Holes.—While a brace with a set of bits and drills is a luxury that you will appreciate very much for quick work, I have found that a coping-saw and a good gimlet will replace them very nicely. See Fig. 1, G and H.

With a brace and bit you need as many bits as the different-sized holes you will cut. For large holes an extension bit would be needed. In the coping-saw and gimlet method, you mark the circle, drill a gimlet hole on the line of the outside edge of the hole, slip the saw blade through and then snap it into its frame. Then as in Fig. 2 you are ready to cut out the plug of wood leaving a circular hole.

The coping-saw will cut much thicker wood than it was intended to cut, and we will use it in our lab. as a wood saw.

Hack-Saw.—For cutting metals like very heavy wire, rods, or plates, the hack-saw is needed.

Tin Snips.—For sheet metal, use a pair of medium size tin snips, which are really very heavy scissors. With these you can, after a little practice, cut quickly and with a straight, smooth edge.

Vises.—*Bench Vise.* This means a small vise that can be clamped on your work bench. It serves to hold

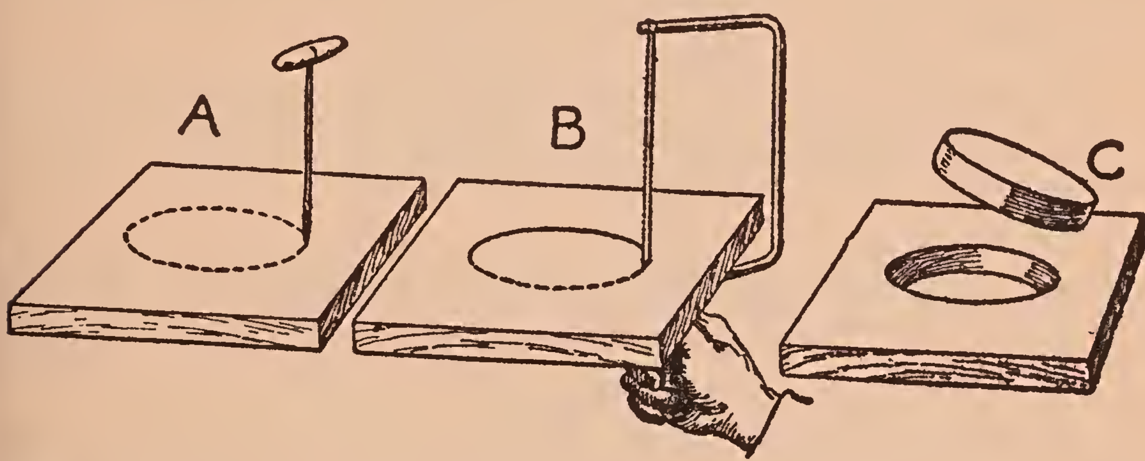

Fig. 2. How to Cut Holes.

material firmly while you hammer, file, fit, or solder pieces together. Fig. 1K.

Hand Vise.—This useful tool avoids a lot of work in awkward cramped positions. When you can't work comfortably at the bench vise, clamp the work in this hand vise and you can hold it firmly yet twist it into any convenient position. The bench vise is more convenient, if you can use it, because it leaves both hands free to work with.

Hammer.—A small mechanic's hammer is much better than the regular tack or nail hammer. Its wedge-shaped end will get down into narrow places. It should be light, else your experiments may not survive its blows.

Clamp.—This iron screw-clamp will hold large flat pieces on the bench in a much more convenient position

than would the vise. It also serves to hold pieces of wood when glued until they become thoroughly dry.

WIRE.—You will not want to run out to purchase wire each time you start an experiment, nor will you want to buy large quantities of certain special sizes until you know what large pieces of apparatus you will be most likely to build.

Before you begin the experiments you should purchase 20 feet of duplex lamp cord, size No. 14 or No. 18. The No. 14 wire is a larger size than No. 18 and will offer less opposition to the current.

You will find this cord contains two conductors each of which is composed of a group of fine wires. This is to make the wire flexible.

Buy 20 feet of *fixture wire*. This is a rubber-insulated solid wire that is used in chandeliers. It will be size No. 18 and be properly insulated so as to safely carry a pressure of 110 volts.

Half a pound each of single cotton-covered No. 22 and No. 18, also a quarter pound of No. 30 single cotton-covered wire will complete your wire supply. To this add a roll of electrician's tape. The small-sized roll will be a sufficient amount.

ADHESIVES.—*Gumstickum* is what boys seem to call them. Shellac cut in alcohol—cut means dissolved—is used to insulate, protect from moisture and stick things together. A half pint goes a long way. Also buy a small can of liquid glue. Keep both shellac and glue tightly corked.

ODDS AND ENDS.—Nails, brads, screws, and metal strips had better be purchased as you need them. Buy a pound of paraffin.

STOREROOM.—A set of empty cigar boxes, properly labelled on the ends, and neatly piled up, makes a fine storeroom for your material, and if you are so lucky as to have a drawer under the shelf for your tools then your lab. will always be in order.

Soldering Outfit.—A small soldering copper, the ¼ pound size is best, some solder in the form of wire, and rosin or a soldering paste that your dealer says does not contain acid, will be needed. For heating the soldering copper you may use a bunsen burner, or an alcohol lamp.

Joining Wires.—For a temporary joint while you are experimenting you may omit the soldering, but do not consider any apparatus that you have made as

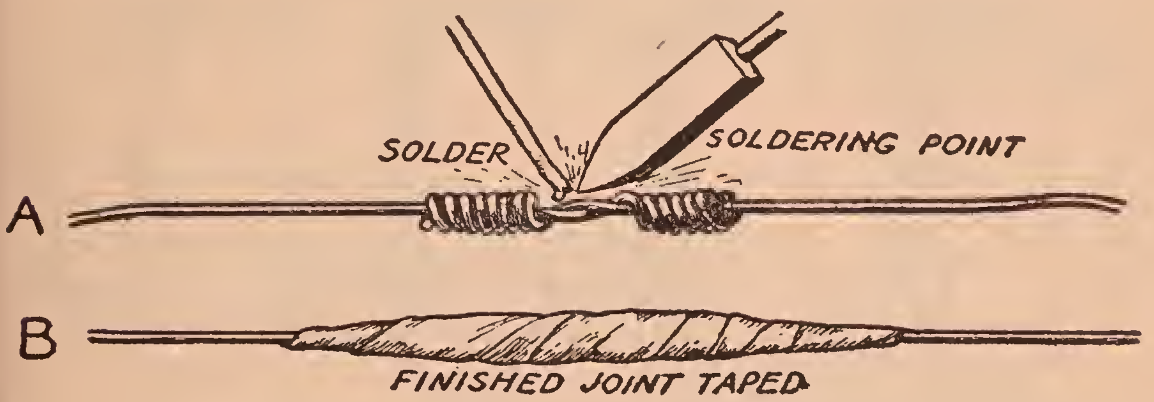

Fig. 3. Soldering Points.

finished until all joints are soldered and binding posts have been attached. To do a good soldering job your soldering copper must be prepared. File the end until it is clean, heat until hot, but not red hot. If the flame turns green take the copper out of flame at once. Rub some rosin or soldering paste on the tip of the copper. Hold the end of the wire of solder against the spot of rosin until a drop or two melts off. With a clean copper wire rub this melted solder on the soldering copper. The solder will spread over the end of the copper. You can now say that the copper is *tinned.* This bright clean tinned surface of the soldering copper is the part you use in soldering things.

Clean the ends of the two wires that are to be joined, twist them together as shown in Fig. 3A. Use clean pliers. Never touch with your fingers a surface that is to be soldered. Rub a little powdered rosin or

soldering paste on the joint. Melt a drop of solder on the copper, and bringing the copper against the joint as shown, hold until the wires get heated and the solder adhers. Do this again on the lower surface and then with the hot copper rub the joint clean. Then when cool wrap with tape as in Fig. 3B. When starting to tape the joint a few narrow pieces may be cut and used to build up the center of the joint to the size

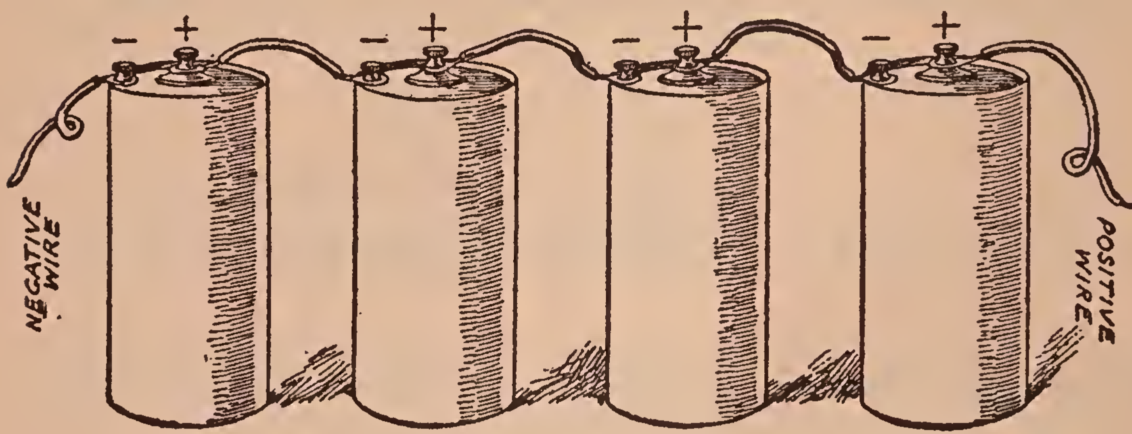

FIG. 4. DRY CELLS CONNECTED IN SERIES.

of the remainder of the joint. This makes the covering smoother and gives a better appearance.

Sources of Current.—DRY CELLS.—For your experiments you need current and at first you must have a perfectly safe source. Four dry cells connected up as shown in Fig. 4 are spoken of as being connected *in series*. Notice that each zinc can is connected to the carbon rod in the center of the next cell and so on. The two wires that go to your experiment come from the terminals of the battery. The positive (+) terminal is the carbon rod and the negative (—) terminal is the zinc can.

STORAGE BATTERY.—Perhaps you have a radio A battery which is a storage battery. This makes a fine source of current. The wire that you attach to the binding post which is marked +, or which on many batteries is painted red will be your positive wire.

Since a lot of damage may be done to the insides of the battery and also a flash of flame produced, if the positive and negative terminals touch each other, you should have some safety device. I will show you how to make one. Remember to make it and use it exactly as directed.

The arrangement shown in Fig. 5 is a good one. You will find it most convenient to place the storage battery on the floor under the bench. Fasten a strip of wood from the bench to the floor and fasten the safety device to this strip of wood. There is then no

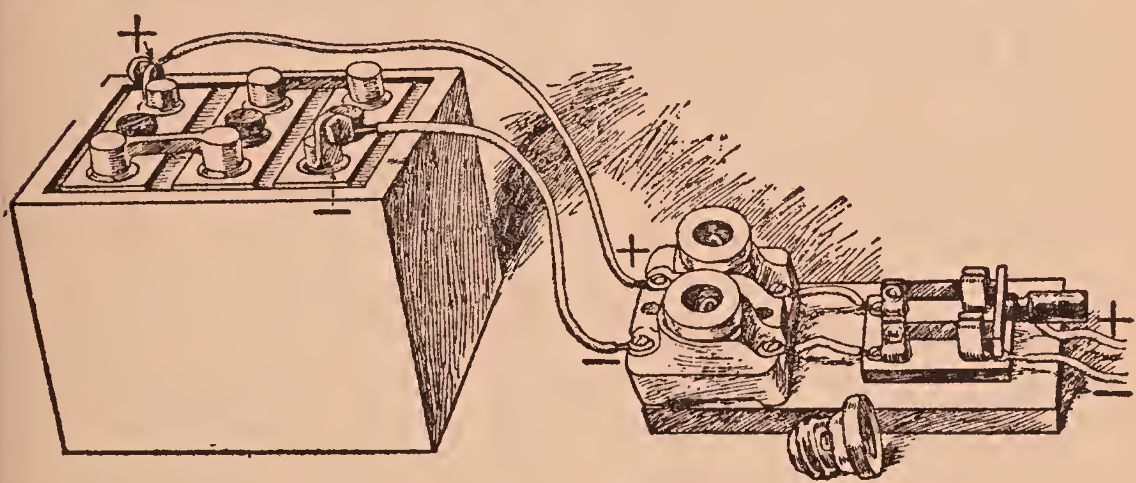

Fig. 5. Hook-up for Using a Storage Battery.

chance of metal tools coming in contact with both blades of the switch, which would injure the battery.

If you must leave the battery where it is, then consider the safety device as part of your apparatus. Attach the experiment to the safety device and then the safety device to the battery.

A Safety Device.—On a board of convenient size place a porcelain, main-line, two-wire plug cut-out. When screwing it down do not tighten the screws beyond the point where the cut-out is held firmly, else you may crack the porcelain. Buy with the cut-out four 3 ampere plug fuses. Place two in the sockets of the cut-out, reserving the others for use if one should melt or *blow* as we say.

The double-pole single-throw 5 ampere knife-switch is attached as shown in Fig. 5. Wire up as shown and mark one wire + and the other —. When in use attach the positive or + pole of storage battery, the one usually painted red, to the + wire of the safety device. Do not allow any metal tools or stray pieces of wire to come in contact with the switch blades.

The switch may have a porcelain or black composition base. Do not buy poorly constructed ones. If a switch is loosely put together you will have bad electrical contacts.

The shopkeeper would call your switch a D. P. S. T. 5 amp. knife, all of which is easy to translate when you know its full name. Double-pole means that there is a blade for each of the two wires or poles of the battery. Single-throw means that the switch opens and closes (throws) in only one way, controlling only one circuit. By 5 ampere is meant that the size of the switch blades is such that 5 amperes of electricity may be cut off and put on, or as we say, a circuit carrying 5 amperes may be opened and closed indefinitely without injury to the switch. Knife refers to the type of switch. It opens and closes somewhat like the blades of a pocket knife.

Using the House Current.—You should not attempt to use the house current for experiments until you have learned to do exactly as you are told and nothing but what you have read in the directions for an experiment.

The storage battery has only 6 volts of pressure or push in it, but the electric light wires of your home have 110 to 120 volts of pressure. If the wires from the storage battery happen to touch by accident it is something like the bursting of a small dam across a small stream. But should such a thing happen to the wires of the house, it would be like a big dam across a deep lake breaking.

The actual danger from 110 volt house supply wires lies in the flash of flame you get when these wires touch each other. It may injure you and start a fire. When this happens, the fuses in the circuit are blown and they must be replaced before the family can get any service from the wires.

For the present, if you wish to use the house supply for experiments, find out from the company that serves you whether you have alternating or direct current supply. If service is a. c. (alternating current) buy a transformer such as is used for toy electric railways. Should the supply be d. c. (direct current) buy a regulator used for the same purpose. Either of these when connected up as in Fig. 6 will give you a proper and safe voltage.

Later on when you have become more familiar with electrical things I will show you how to build a 110 volt control panel.

The Transformer shown in Fig. 6 is connected to the house current by screwing the attachment plug into any convenient lamp socket on an alternating current supply line.

As you swing the lever over to the contacts marked B, C, D, E and F, the pressure at the terminals H and K becomes greater. You will understand better why this is so by looking at the diagram of the interior of the transformer.

Connected to the 110 volt line is a coil of many turns of fine wire. Only a small current flows because the resistance of this coil is high. This coil is wound on a frame of soft iron and on the same frame is wound a coil of fewer turns of coarser wire.

Due to the magnetism generated by the many turns on the 110 volt side of the transformer, power is transferred to the other coil. A much lower voltage is produced because the other coil has fewer turns.

Since the voltage depends on the number of turns

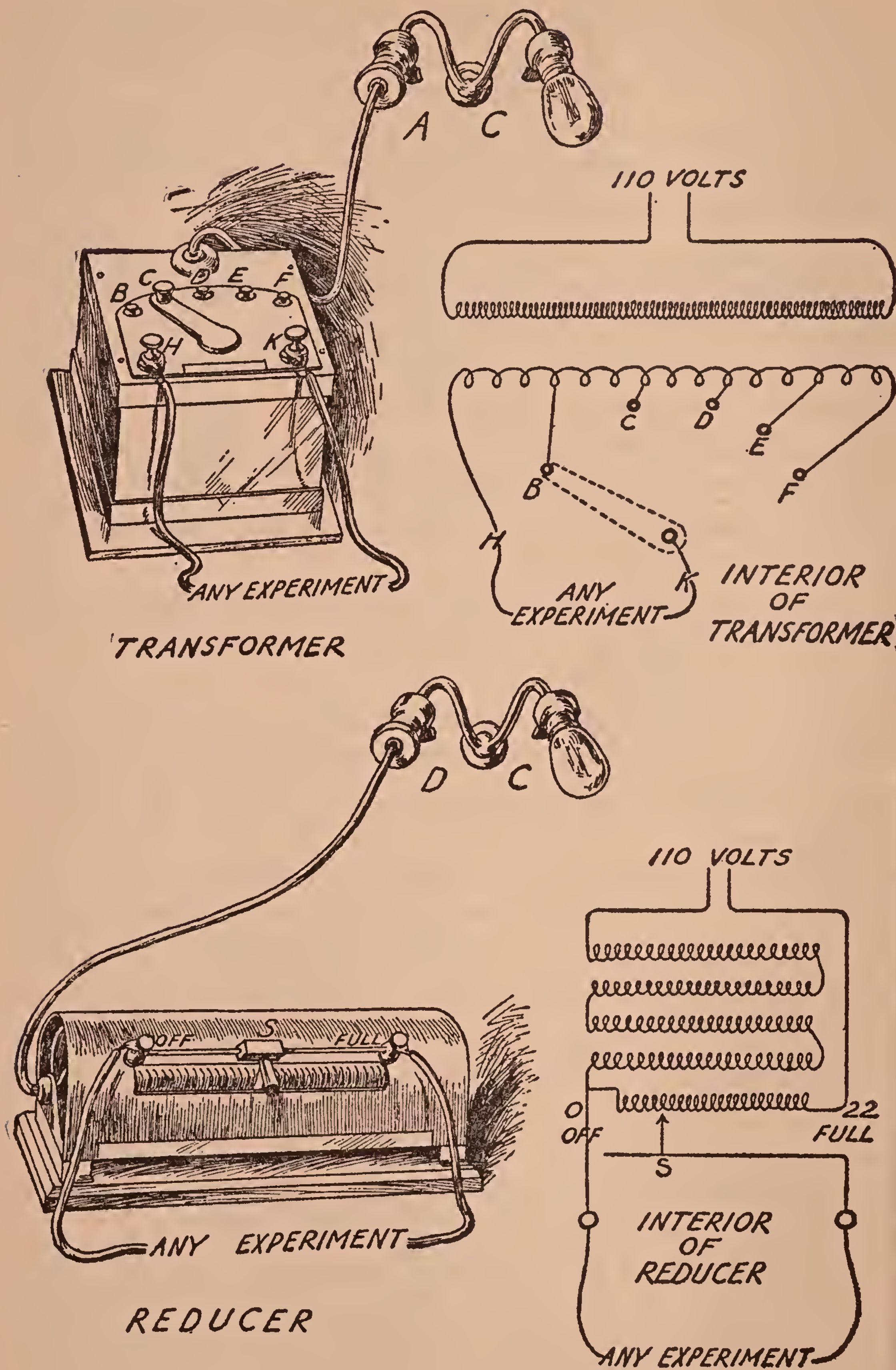

Fig. 6. Hook-up for Using 110 Volts.

in actual use, as the lever is moved over, the voltage at the terminals H, K changes from 4 to 7, to 10, to 13 and finally with the lever on F we get 15 volts at H, K.

The Reducer.—When your home has a direct current supply a transformer will not operate. You then use a reducer. This is a resistance or an opposition to the high voltage of the 110 volt line so arranged that you can not possibly get that voltage applied to the trains or the experiments.

One type of reducer is shown in Fig. 6 with its attachment plug screwed into a socket attached to a direct current service. The sliding switch regulates the pressure sent to the experiment.

The interior view shows five coils of wire each of which uses up 22 of the 110 volts. If you should touch the ends of any one of these coils these 22 volts will send a current through you, but such a small one that it would not harm you. You could just feel it sting.

From the diagram you will see that the binding post marked *Full* is connected by a bar to the slider S and that this bar does not touch the *Off* post. It is supported there but insulated from it electrically.

If the slider is in the position shown in the view of the outside of the reducer it is collecting 11 volts for the experiment. In the position shown in the interior view, the slider is collecting about 5 volts. Way over to the right the slider would place 22 volts of pressure on the experiment, and way over to the left you will get no pressure at all.

Whether using the transformer or the reducer for experiments, consider it as a battery and connect the terminals of these devices to the fuse block of the safety device shown in Fig. 5 and attach your experiment to the other end of the safety device.

This will avoid damage to the wiring of the expen-

sive transformer or reducer, replacing that catastrophe by the blowing of a cheap fuse.

The Reasons for Experiments.—There are two sides to the study of electricity, the practical and the theoretical, the doing of things and the knowing why they happen. These two aspects of science should go together. A very studious chap may read this book through before doing any construction work or experimentation. I think the average fellow will want to try things out as he goes along. This is the better way, for then you see for yourself that things work the way the descriptions say that they will.

Seeing Is Believing.—Facts that seem hard to believe when only read about become clearer when you talk them over with a chum; but an experiment makes them real facts. You get the idea then at first hand from Nature itself, working through your apparatus. Therefore do the experiments.

A Help to Understanding.—Theories may seem hazy when descriptions are read. Although no experiment that you do may prove the theories, yet you get an insight into things that helps wonderfully in understanding them. You may sit and think getting no nearer an understanding. Do an experiment which depends on this theory for an explanation of how it works, and your mind will be guided along the proper lines and you will begin to see not only the *how* but the *why* of it.

Trying Anything Once.—This is not the real spirit of scientific investigation. You should be willing to try and try. If the experiment does not work out as it should perhaps some little thing is at fault. Look over the hook-up and find the trouble. An experiment may be performed many times with lots of fun each time, and with a greater understanding of the principle involved. Try it thrice should be your motto.

Hook-Ups.—If you will glance at Figs. 9 and

10 of the next chapter, you will see that they are simply diagrams. They show instruments and cells by some form that suggests the desired article to your mind. These drawings show how to "wire" an experiment or, as it is sometimes expressed, they show how to set up an experiment. The old name for such drawings was "wiring diagram" and the very latest name is "hook-up."

In hook-up sketches or drawings we use "conventional signs" for pieces of apparatus, rather than actual pictures of them. We thus save a lot of time and when one becomes accustomed to the signs they are just as clear as the pictures.

When, as in Figs. 4, 5 and 6 we are making a sketch of a hook-up of unfamiliar things, or perhaps I should say things not familiar to the other person, then we make actual pictures of the things.

After doing an experiment, if you find that your arrangement of the pieces of apparatus was different from the hook-up given in the book, but that as far as the flow of electricity was concerned the hook-up was the same, then draw in your note book a hook-up of the experiment just as *you* performed it. This will enable you to do the experiment again without waste of time.

CHAPTER II

GETTING DOWN TO BUSINESS

LET US BUILD SOMETHING
The Galvanoscope
The Galvanometer
MAKING A GALVANOSCOPE
Experiment 1
The Winding Reel
Paraffining the Coil
Glue, Screw or Nail
The Frame
Astatic Needles
The Galvanometer Scale
WHAT WILL WE DO
CELLS CONNECTED IN SERIES
Experiment 2
Measurement of Pressure
HOW CURRENT AFFECTS THE GALVANOMETER
Experiment 3
Measurement of Quantity
BACK TO THEORY AGAIN

CHAPTER II

GETTING DOWN TO BUSINESS

Let Us Build Something.—About the first thing that you will want to know when you begin to experiment will be whether there is any current flowing, and in what direction it is going. Later on you will want a current measurer that will be quite exact, but for the present you can construct a *galvanoscope* and use it as mentioned above. You may also construct a resistance coil and a shunt which will enable you to use this instrument as a fairly good *galvanometer*.

THE GALVANOSCOPE.—This instrument, named after Galvani, an Italian scientist, means an instrument making electricity visible. The Greek word *skopeo,* which we spell *scope,* means to see.

THE GALVANOMETER is an instrument that measures current. The Greek word *metron,* which we use as *meter,* means to measure.

Experiment 1.—HOW TO MAKE A GALVANOSCOPE. —Cut a piece of cardboard 7½ inches long and 1½ inches wide. The corners must be square and the sides parallel. Lay this on the work bench before you and draw lines across it. Starting at one end draw lines at ¼, 1¼, 3¾, 4¾ and 7¼ inches from one end.

The cardboard will now look something like Fig. 7A. The marks will be as shown ¼ inch from each end, 1 inch and 2½ inches apart.

With a sharp knife crease deeply at all these lines, about one-third the way through the material. At the

place shown in Fig. 7A cut a slot 1½ inches long and ⅜ inch wide. Now fold the cardboard into a frame. Paste the quarter inch overlaps to hold the box securely. Fig. 7B.

The Winding Reel.—To properly wind this coil and the others that are to follow, you will avoid a lot of trouble from kinks in wires if you will take a few moments now to make a proper winding reel.

At the right-hand side of the work bench make a gimlet hole. Enlarge this with the coping-saw until a pencil or a slender dowel rod will fit into it. Under the hole nail a piece of wood so that the rod cannot fall through. Should rod fit a little loosely in the hole, plug the hole with match sticks until the rod is held firmly.

Over the rod slip the spool of a half pound of No. 22 single cotton-covered copper wire. See Fig. 7C.

Slip the fingers of your left hand into the cardboard frame, and leaving an end of wire about 6 inches long free, begin to wind the coil. Start on the left side of the slot. Wind a layer of 8 turns and then two layers more, making 24 turns in all. Secure this coil with some slips of electrician's tape.

While winding, the wire should have unwound from the spool smoothly as the spool revolved on the rod. Watch carefully for loops forming, which as you pull on the wire will change from the loops of Fig. 7D to kinks like the one in Fig. 7E. Even if you smooth out such a kink there is always danger that the wire will break at that place. The sharp bending weakens the metal very much.

When the twenty-fourth turn is completed bring up the wire across the end of the frame so that the twenty-fifth turn will start next to the slot and on the right side of it. Secure this cross-over wire with slips of tape. Wind as before 24 turns in 3 layers of 8 turns each. The frame and coil now appear as in Fig. 7F.

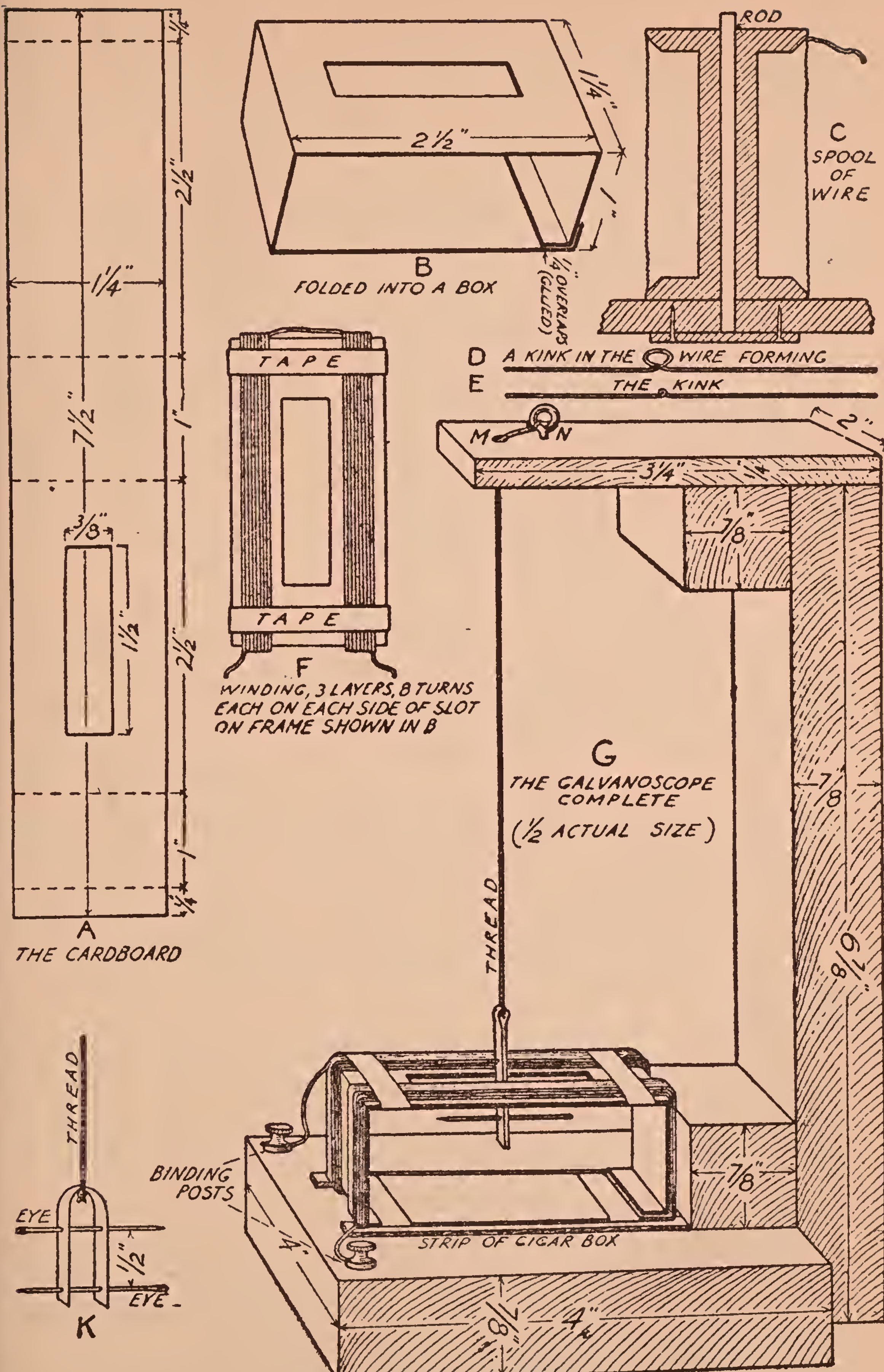

FIG. 7. THE GALVANOSCOPE.

Paraffining the Coil.—This is a job that you will be doing quite frequently in the course of your experiments, so learn how to do it neatly. First tie the coil at several places with thread because the hot paraffin may cause the slips of tape to come off.

In a metal cup melt enough paraffin, or parawax as some stores call it, to at least allow more than half the coil to be submerged. Melt the paraffin but do not heat to a higher degree of temperature. It is hot enough when it becomes liquid and you may easily heat it to a temperature hotter than boiling water.

Using two pairs of pliers dip the frame and coil into the melted paraffin and hold over the cup to drain. When cool it will be ready to mount. The paraffin will protect the windings, hold them in place, and make them damp proof.

Glue, Screw or Nail.—When constructing the wooden parts of apparatus the question arises as to what is the best way to fasten different pieces together.

Gluing.—If wood surfaces are smooth, dry and free from grease, a very thin coat of liquid glue will serve to stick the pieces together as strongly as nails or screws would have done. Glued joints must be clamped together and left in the clamp at least a day and a night.

Such a joint is strong, has no projecting nail or screw heads, and apparatus fastened in this way is not magnetic.

Screwing.—This is the next best method of fastening wood to wood. To make a tight, strong screwed joint without splitting the wood requires slow and careful work. The following method is a good one, for it has been used many times on difficult jobs.

When you buy screws of a particular length you will find that you can get them in many thicknesses. Select slender ones as they have less wedging action and hence less tendency to split the wood. Round-headed blued screws make the neatest job. The head need not be

sunk into the wood, and thus there is one less thing to do. These dark blue screws give a fine appearance at less cost than brass ones.

Hold the pieces in their proper places and mark on the top piece where you intend to put the screws. Heat a steel knitting needle red hot and burn holes through the top piece.

Place the pieces together again and through the holes in the top part mark where the screws will go into the lower part. Separate the pieces and with a gimlet make holes in the lower part. Work slowly so as not to exert a sidewise or splitting force. Do not press hard, take it easy. Do not burn the holes as the charcoal on the edges of the hole won't hold the screws.

If you are using round-headed screws place the pieces together and slowly twist the screws in place. Do not force. Enlarge the holes if necessary. Should you get the holes too large a sliver from a match stick, dropped into the holes will make the screw bite and secure a tight fit.

If you are using flat-headed screws, "counter sink" the heads. This means make a hole to receive the head so that on the finished job the top of the head of the screw will be flush, that is level, with the wood.

To do this, select a large wire nail whose point is about as large as the head of the screw. Clamp it in the hand vise and using it as a drill enlarge the top of the hole that you burned, just enough to receive the head of the screw. Some times heating the point of the nail to burn the wood will help you, but this is apt to discolor the wood around the hole.

When the screw is firmly in place the head should be flush with the wood. Sand paper the job a little and a neat workmanlike result will be obtained.

Carelessly drilled holes and unevenly driven screws will result in the two pieces taking a position a little different from that which you intended them to take.

This may not spoil the experiment, but you cannot be proud of the apparatus.

Nails.—The only type of nail used in small apparatus is the *brad*. All slender wire nails with narrow heads come under this name. They are so slender that they will not split good wood and may be driven in, flush with the surface of the wood. Drive all brads straight down through the upper piece until the points are just through. Then place the pieces together and again drive straight down. The final blows, setting the head in flush, should be light ones else you will dent the wood.

The Frame.—Make a wooden frame and base as shown in Fig. 7G. The sizes need not be just as given. If the available pieces of wood are somewhat near these sizes go ahead with them and thus save lots of time that otherwise would be used in cutting and trimming the wood. But make it neatly. Good electrical qualities usually go with good mechanical workmanship. Drill, or better yet burn the hole at M with a steel knitting needle or slender wire nail. Burning holes in thin wood has the advantage of never splitting the wood. Have the metal red hot at the tip, press hard on the wood and repeat as soon as metal cools. At N put a small screw eye. Put on the two binding posts at corners of the base board.

Astatic Needles.—The proper way to magnetize the two sewing needles would be to stroke both at the same time. This, however, makes them so nearly alike that when used as a pair of *astatic needles* they are much too sensitive for us. So we will give one of the needles an after treatment of a couple of extra strokes.

The actual process consists in holding the two needles together, eye to eye, point to point. Stroke, but do not rub, the needles with one pole of a permanent magnet. Stroke from end to end, lift magnet and repeat.

After about ten strokes, drop one of the needles and give the other several more strokes in same direction with same magnet pole as before.

From a calling card cut a piece two inches long and not quite a quarter of an inch wide. Bend in a U similar to but not exactly the shape shown in Fig. 7K. Stick the needles through from opposite sides. Tie a thread of darning cotton through a hole in the top. Hold up the combination or magnet system, as we shall call it, and if it does not hang straight, push the needles in or out, or trim the card holder.

Slide the thread through the hole, tie end to the screw eye so that by turning the eye you raise and lower the magnet system. Raise the magnet system up out of the way and slip the coil and frame into place. The coil may wobble because it is unevenly wound. Block it up under each end with slips of cardboard or thin wood nailed to base with brads.

Have a few lumps of paraffin ready and a warm soldering iron. Hold the frame in place. Lower the magnet system into it. Adjust the height by the screw eye. See that frame is so placed that the magnet system is free to turn. While holding the frame with left hand lay a few lumps of paraffin on base against coil frame. With the warm soldering copper melt the lumps of paraffin. As they cool the frame will be securely held to the base. The trick is to have the soldering copper just a little cooler than you think it ought to be.

Solder the free ends of the coil to the binding posts. Give all the wood a coat of shellac. You now have a galvanoscope so sensitive that you will have fun finding currents weak enough not to send it spinning around.

Prepare also another piece like Fig. 7K. Instead of the two needles, replace the lower one by a magnetized piece of steel knitting needle. The place of the upper one will be taken by a broom straw from a whisk broom. This magnetic system will be less sensitive

than the other and better adapted for the making of measurements of the pressure and quantity of electricity.

SCALE FOR A GALVANOMETER.—To use the galvanoscope for a meter or galvanometer we equip it with the

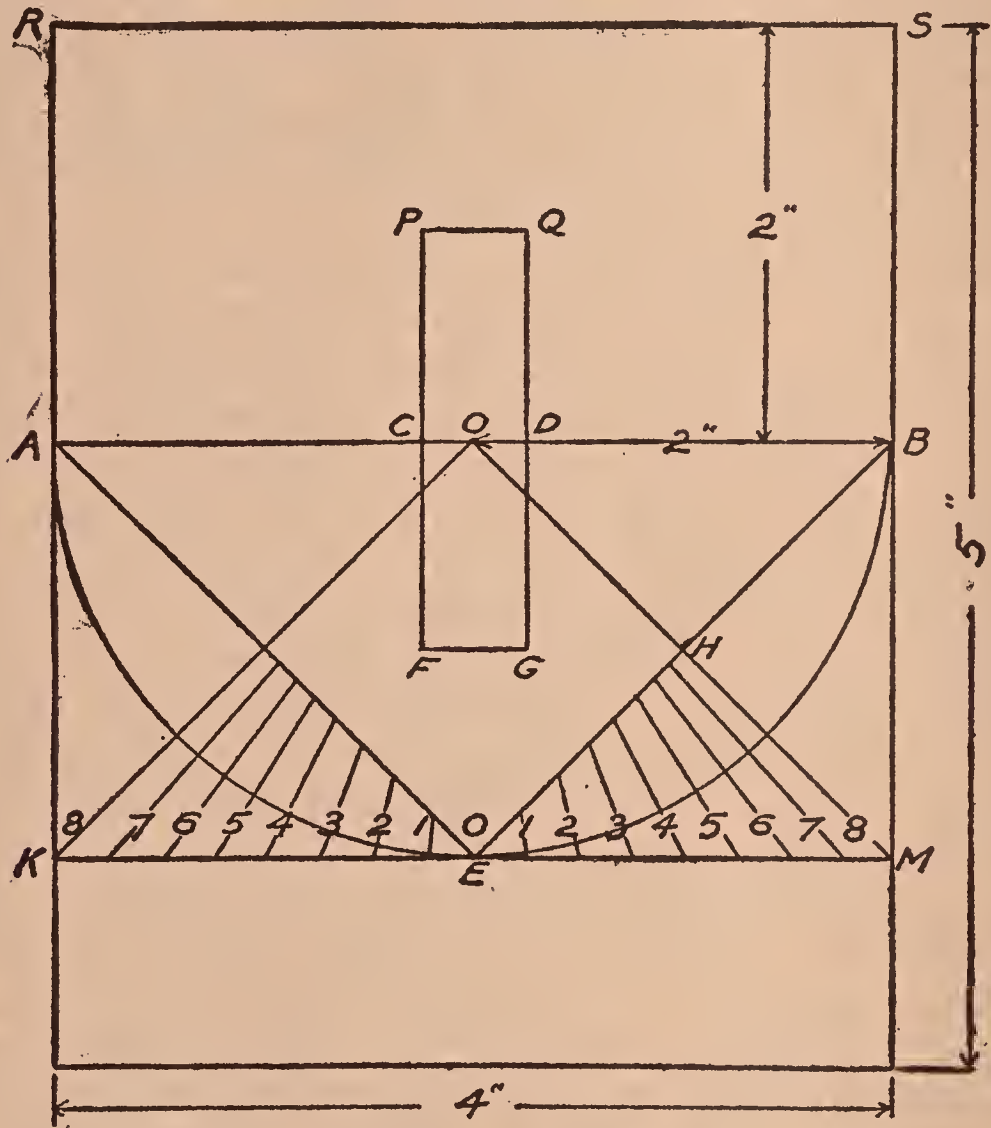

FIG. 8. SCALE FOR A GALVANOMETER.

knitting-needle broom-straw magnetic system and a *scale.*

As shown in Fig. 8 upon a piece of cardboard 4 x 5 inches we draw a half circle, a semi-circle as it is also called. The diameter AB is 4 inches long. From O the center of AB, mark off OC and OD each ¼

inch. Draw OE at right angles to AB or as we say perpendicular to it. OE will of course be 2 inches long. At 1 inch out on OE draw the line FG as shown. Draw BE and find its middle point H and draw the line OHM. Draw the line KEM which is at every point 2 inches away from AB. By halving EK and halving the halves several times you will get a series of points on EK. From these points draw lines down towards O about as far as line AE as shown in Fig. 8. Mark E, 0 and K, 8 and the other points 1, 2, 3, 4, 5, 6, and 7. Do this on the right hand side of card. Draw PQ like FG. Draw FP and GQ. Cut out the part PFGQ with a sharp knife or scissors. Cut off the part of card beyond line KM.

On the block behind the coil and frame of the galvanoscope in Fig. 7, glue slips of cardboard until when you lay this scale on them it will rest evenly on the upper surface of the coil. Place so that the point where O was, is where the thread is. Sounds queer but it's perfectly all right. Have RS over block, KM towards you. When you are sure you have the position correct, then remove the scale, spread glue on the cardboard slips and on lower side of scale. Adjust scale again and place all away to dry.

What Will We Do? Now that you have built a galvanoscope what shall you do with it? That depends on where you are in the book. I have assumed that while making this instrument you have taken time to make a good job and that perhaps in between work on it you have been reading the book.

You will not understand all about the operation of this instrument until you have finished Chapter X. But I wanted you to have it ready to experiment with and to be able to see how facts told in the book apply to it.

You may do Experiments 2 and 3 now and do them again later on; in fact you may repeat them many times,

understanding the better why things happen as they do, the further you are along in the reading of the book.

Experiment 2.—To observe the effect of connecting more and more cells in series; place the knitting needle magnetic system in the galvanoscope and turn the instrument until the broom-straw is over the 0 mark of the scale.

Look at Fig. 9. This diagram is what is called a hook-up. The actual pictures of things are replaced by certain *symbols* or *conventional signs,* as they are also called. G is the galvanoscope. A a coil of wire.

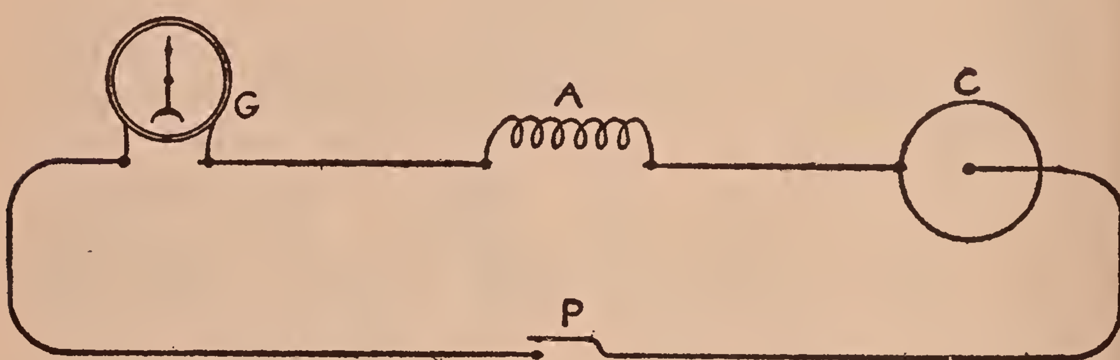

FIG. 9. HOOK-UP FOR MEASURING PRESSURE.

C a dry cell. The way they are connected so that the electricity from the cell goes through them all, one after the other, is called *in series.*

To make the current flow and to stop it, or as we say to "break" the current, there is a push button, switch or telegraph key at P.

The coil A will be the spool containing the quarter pound of No. 30 wire that you purchased.

When you *close the circuit,* which means make a continuous path for the current, by the push button at P, I cannot tell you just what the galvanoscope will do.

The amount the galvanoscope will move depends on the strength of the magnet, the weight of it and the

broomstraw, how difficult it is to twist the thread of darning cotton and finally on the amount of wire you have used to connect the parts of the circuit together.

Also if your cell is not a new one it may lack the proper pushing ability.

I do not want to give you exact directions nor tell you too much. Remember that you are experimenting. To a certain extent you are off on an electrical adventure of your own. I wish you to try to rely on yourself as much as possible in this experiment.

The galvanoscope will either move or it will not move. If it does not move, remove the coil A and connect the ends of the wires to complete the circuit. If the galvanoscope does not move now it is because there is a break in the wires some where. Find that break or place where the wires do not touch and repair the break.

Suppose it moves a lot when you take the coil A out and does not move perceptibly, when the coil A is in the circuit. That would make me happy, for then you have a real job ahead of you. The job is to use enough of the spool of No. 30 wire wrapped on an empty safety-match box, so that using it as coil A, the cell moves the broomstraw over near the number 2 on the scale.

We say then that the galvanoscope *reads* 2 or that the *deflection* was 2.

When you have done this, paraffin the coil, mount it on a board with binding posts and label it Voltmeter coil A.

Let us suppose that you have your galvanoscope working properly using the coil A and that one cell gives a convenient reading which you have written down.

Open the circuit at P and not disturbing anything else insert another cell at C. Look back at Fig. 4 so that you will get them in series. Note that two cells

give a greater reading or deflection as it is also called. The word deflection means the amount of rotation of the magnet from its position of rest when nothing is connected to the instrument to the place where it comes to rest after the cell or cells are connected. The straw pointer, of course, makes the same rotation as the magnet.

The deflection really means the size of the deflection, so the instrument should read zero before you close the circuit. Then the reading with circuit closed will be the deflection.

On a card, or page of your note book make a heading,

MEASUREMENT OF PRESSURE.

Copy the hook-up of Fig. 9 neatly and then make a heading and table of readings like the one below.

Galvanoscope with Coil A in Series

Deflection of.............means 1½ volts
Deflection of.............means 3 volts
Deflection of.............means 4½ volts
Deflection of.............means 6 volts

When you had one cell in the circuit you could assume that the pressure, measured by a quantity called a volt, was 1½ volts, so when two were used the pressure was twice as much. This tabulation when filled in by your experiment will enable you at some future time to find the pressure given by some other battery.

HOW CURRENT AFFECTS THE GALVANOMETER.—*Experiment* 3.—We are now preparing to observe what a greater quantity of electricity will do when tested by a galvanometer.

Set up the apparatus as shown in Fig. 10 except

that you are to omit the wire S. See what the galvanoscope does. If the reading is more than 2 on the scale you must use the wire S. We will call this a *shunt* and explain about shunts later.

Fasten a piece of No. 18 wire between the binding

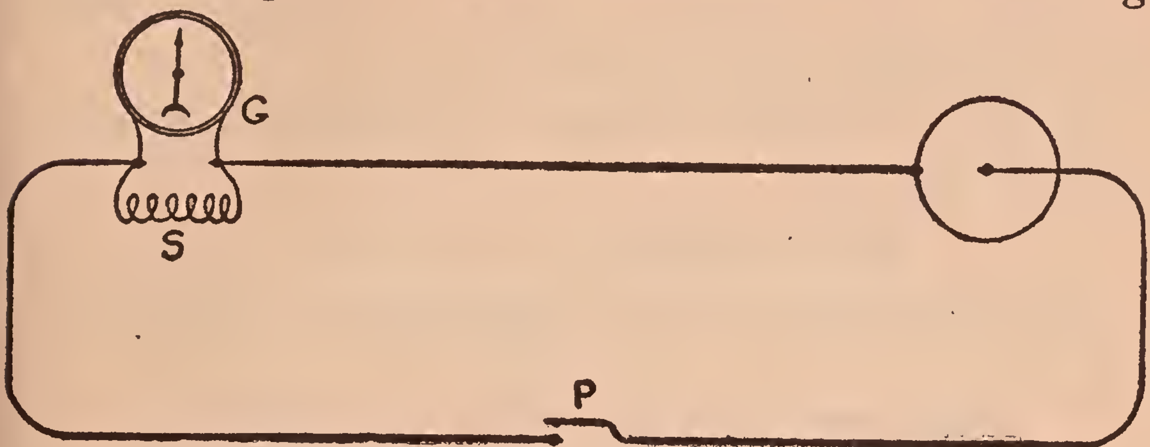

FIG. 10. HOOK-UP FOR MEASURING QUANTITY.

posts of the galvanometer just as S is attached in Fig. 10. How much wire? I cannot tell; it depends on many things, as in Experiment 2.

You must by use of a *shunt*, S, reduce the current in the galvanoscope until its reading is about 2 on the scale.

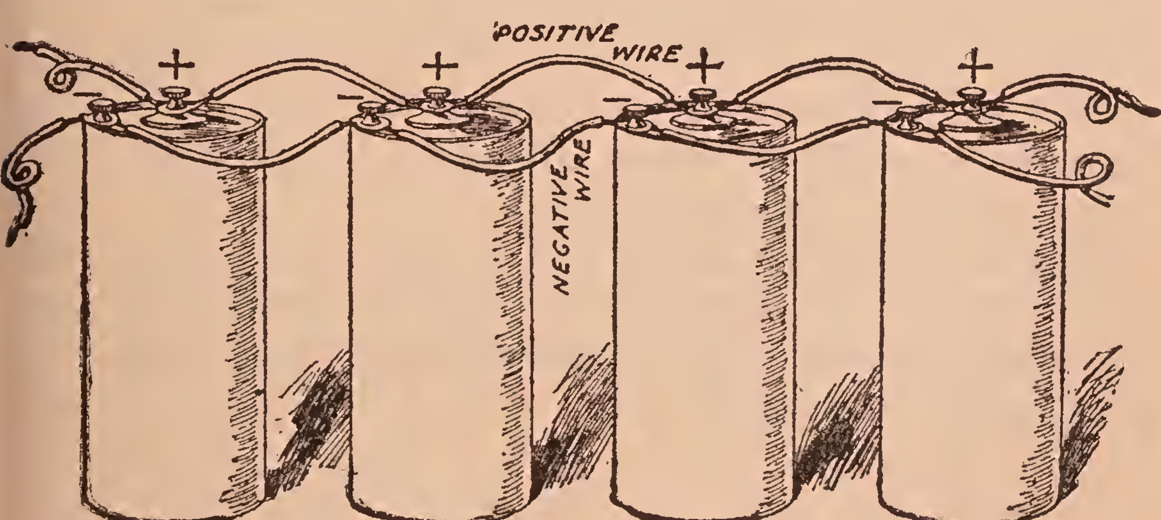

FIG. 11. CONNECTING CELLS IN PARALLEL.

You must by experiment find out that the shorter the wire S is made, the more current flows through it and the less through the galvanoscope. The longer S the more the galvanoscope will read.

When you are satisfied with the reading caused by one cell, use two cells connected in parallel, then three cells connected in parallel.

To get the parallel hook-up correct, connect the cells as shown in Fig. 11.

Notice that it would be correct to say that the shunt S is *in parallel* with the galvanoscope.

A card or notebook page should now be prepared with the heading:

MEASUREMENT OF QUANTITY.

Copy the hook-up of Fig. 10 and make a tabulation.

Galvanoscope with Shunt in Parallel.

Deflection of............means current from one cell
Deflection of...........means current from two cells
Deflection of..........means current from three cells
Deflection of..........means current from four cells

When you remove the shunt wind it on an empty safety match box, paraffin it and attach to a small board. Fasten the ends of the coil to the board allowing six inches of each end of the wire to be free. You can then easily attach the shunt directly to the galvanoscope. Label this coil, Ammeter Coil S.

Back to Theory Again.—We must now leave our work bench and learn more about electricity so that we may experiment again with a greater understanding of what we are doing.

CHAPTER III

WHAT ELECTRICITY IS

The Old Idea
The New Idea
    Some Proofs
        Experiment 4
    Electro Chemistry
        Experiment 5
The Idea You Are to Get
    Experiment 6
    Clinching the Argument
The Make-Up of Matter
    Electrons
        Cause of Light
        Cause of Magnetism
    Atoms
    Matter Not Solid
        Experiment 7
        Experiment 8
    More About Atoms
The Make-Up of Electricity
    Definition of Electricity
    Protons
    Electrons
Electrical Charges
    How to Get Charges
    Actual Methods Used
Different Kinds of Electricity
    Static Electricity
        Static
    Current Electricity
        Juice
    Their Differences
    Direct Current
    Alternating Current
    Cycles
    Frequency
        Low Frequency
        High Frequency
        Radio Frequency
        Audio Frequency
Electricity Known by its Effects

CHAPTER III

WHAT ELECTRICITY IS

The Old Idea.—Were this chapter written when I was a boy, one would confess ignorance as to what electricity really was, and say that it was something that did certain things; that when magnets, motors, lamps and such things were in operation it was a something called electricity that did the work.

Today we know more about the internal structure of matter, and this has led us to a knowledge of what electricity is.

The New Idea.—Perhaps electricity is matter or matter is electricity, whichever way seems best to you. I feel sure that electricity is the material of which our world is made. "Why, how can that be?" you say. "There are so many different kinds of substances—sugar, salt, gold, lead and so on; surely if they were all made of the same thing they would be alike." I do not blame you for thinking this, but let us think over some things.

Some Proofs.—I can tell you of some things composed of the same substance and yet acting quite differently. We are now about to take a little side path and roam into chemistry for just a few minutes. This is perfectly all right, for the chemists will tell you that electricity is the thing that makes their chemicals work.

You need not do these experiments, as they are not electrical ones in the sense that you use the word electrical; they are chemical ones. Should reading them create a desire to read up about chemicals and do some chemical experiments, buy a copy of "The Boys' Book

of Chemistry" and you will have a delightful and profitable time with it.

Now, to prove that things can be made of exactly the same stuff and yet be very different.

Experiment 4.—Make some oxygen by dripping water on sodium peroxide or oxone, as it is often called. Fill a glass tank with this oxygen and let a leak between two high voltage wires take place in the tank. This leak is called a silent discharge. When the tank is opened the oxygen has turned to ozone.

Oxygen and ozone smell differently and act differently. They are two entirely different substances, yet each is composed of exactly the same stuff. It is as uncanny as if you held three dimes tightly in your hand, shuffled your feet over the carpet, touched your knuckles to the gas or electric light chandelier and after the shock was over opened your hand and found two bright new 15-cent pieces, coins that you never saw before.

To return to our oxygen and ozone experiment. "Yes, but," you want to say, "did not the electricity do something to the oxygen and change it by putting electricity into it or taking it out, and thus produce ozone?" "Well, suppose it did?" say I. "Then something with electricity is oxygen and this something with more or less electricity is ozone." That suits me, for this is just what I believe. I believe that one stuff can make two different things if the amount of electricity in it is changed, and furthermore I say, "Perhaps the original stuff itself is nothing but electricity. Experiments by clever scientists lead us to that belief."

Electro-Chemistry.—"I thought this was going to be a book about electricity, but it seems to be chemistry," I hear my reader say. I reply that I know that your radio A battery and radio B battery, the battery that rings your door bell or the call bells and buzzers

in Dad's office are electro-chemical devices. I know that all the copper wire you use is made by an electro-chemical process. So don't worry. This little bit of chemistry will come in handy before you finish this electrical book.

Experiment 5.—The following experiment also shows that the same stuff can make two different things.

Yellow phosphorus or, as it is sometimes called, white phosphorus, is an amber-colored solid which catches fire very easily if warmed to a temperature of 95 degrees Fahr. It must be kept under water else it fumes, giving off a poisonous vapor. It produces burns that are poisoned and hence very hard to heal. It will dissolve in carbon disulphide.

If this yellow phosphorus is sealed up in a retort and heated to 570 degrees Fahr., when it is taken out it is a chocolaty-red color. It is not poisonous and won't catch fire until heated to 660 degrees Fahr. It won't dissolve in carbon disulphide. There you are, two different things made of the same stuff.

The Idea You Are to Get.—So keen am I on getting you to see that the idea of all materials being made of electricity in different amounts and different arrangements about the central pieces is not any harder to believe than any other explanation offered, that I will give another experiment that, like the others, is designed to show that the self-same stuff can make different materials.

Experiment 6.—Heat some powdered sulphur so gently that it melts to a pale yellow thin liquid. Raise its temperature from 235 degrees Fahr. slowly to 356 degrees Fahr. and the sulphur will become a thick dark brown liquid so thick that you may invert the test tube for a few seconds and the sulphur will not run out.

Heat more and the sulphur thins to a dark brown liquid which begins to boil at 830 degrees Fahr. Pour this liquid into a pan of cold water and examine it.

You started with a hard yellow crystalline solid; you have had several substances and you now have a dark brown chewing gum-like mass, almost like rubber.

Clinching the Argument.—I now want you to say, "If I do not *yet* believe these things he is perfectly capable of describing another experiment." You are right, boys, I can tell you of another case where two different materials are made of the same stuff. So we agree, you boys and myself, that perhaps electricity is the thing that all materials are made of. We also agree that perhaps copper, carbon, and zinc are composed of particles of electricity.

The Make-up of Matter—This is just about the right time to grapple with molecules, atoms, and electrons, for looking out of the window I see something that gives me a bright idea.

I see a swarm of little insects called gnats, and they are swirling around in a cloud. How like an atom they are! All of these insects seem to be whirling around in the cloud, but a closer view shows that near the centre there are a number which merely zig-zag forwards, backwards, and, may I say, edgewise. I notice some at the outer edge of the swarm that seem to hover near one spot. What a wonderful atomic model they make! Keeping this swarm in our minds let us discuss electrons.

Electrons.—An electron is a definite quantity of negative electricity. It is also the smallest particle of negative electricity that exists. How big is it? It is so small that it is hard to tell with ordinary decimal fractions how small it is. Let us call it just two ten billionths of a centimeter in width. The weight of an electron is beyond me to write. When expressed as a

fraction of a gram, it is about one million billionth of its size. Just how little this is I cannot imagine. Can you?

These electrons are all alike, whether they live in an atom of copper or an atom of zinc they care not. Any place where one can hang its hat is home. They are attracted by any nucleus, and oh my, how they dislike each other.

Dry cells, wet cells, storage batteries, dynamos, and generators all push and shove these electrons on in a continuous stream, when the proper conducting path is furnished. Reminds me of traffic on a busy day in a one way street where all the cars are flivvers.

When the proper electrical path is cut and a gap is formed, these cells and other devices pile crowds of electrons up at the gap, like the street when a traffic cop says "Stop" and the flivvers all crowd up treading on each other's tires.

Please remember that electricity, as you know it, consists of tiny specks of electricity of tiny but definite mass and size, all alike and all repelling each other.

You will see then that electricity can not be spread evenly over things, like butter on bread, but is more like the tiny specks of sugar when granulated sugar is sprinkled on bread.

Cause of Light.—As the electrons rotate about a nucleus something may cause some of them to rotate in a smaller circle or orbit. The electron needs less energy to rotate now, and being a spendthrift, throws this extra energy, which it has, but does not need, off into the universe. This radiation may, under certain conditions, affect our eyes as light.

Cause of Magnetism.—We firmly believe that these rotating specks of electricity also cause what you call magnetism.

Atoms.—The materials around us are not solid. They are made up of separate pieces called atoms.

Even the dense materials are as porous and open-meshed as the swarm of gnats that I was observing some time ago. No, I am not joking. Of course these materials look and feel solid, but they are not really so. We cannot see, nor can we feel the openings because they are so small.

Let us imagine a giant a million times your size living in a world where all things are in the same proportion. Suppose that some day he picked a leaf off a mulberry tree in his world. This leaf would be three million inches long, which is 47 miles. A scientist in the world of giants might, by a series of most delicate experiments, find that a few of *our* silk worms were present on *his* leaf. He could not see them with his microscope, but certain electrical effects would indicate the presence of a few specks of something. More delicate experiments would show that when this something changed its position there seemed to be a dragging force acting on it. Further investigation would indicate that there was a different something forming around the original something. So as the silk worm spun its cocoon, the scientist would know that something was being surrounded by something, yet could not see nor would he ever hope to see these somethings.

To such a giant a piece of our honey comb would appear and feel solid. An old automobile radiator from one of our cars would also appear smooth and solid to him. But his scientist would tell him that it really was rough and was quite porous. So you see, things are not always what they seem.

MATTER IS NOT SOLID.—*Experiment 7.*—Turn your bicycle upside down so that it rests on the handle bars and the saddle. Just for fun thrust a pencil back and forth through the spokes of the rear wheel. Now turn the pedal rapidly and look at the rear wheel. Can you

thrust your pencil through between the spokes? No. They move so fast that you cannot see them nor can you see the spaces between them. Nor can you poke a pencil through.

There you are. As I said, small pieces in rapid motion can give the appearance of solidity, and the non-poke-through-able property of solid bodies.

Here is an experiment to show that solid bodies are either full of small holes, or else can have small holes

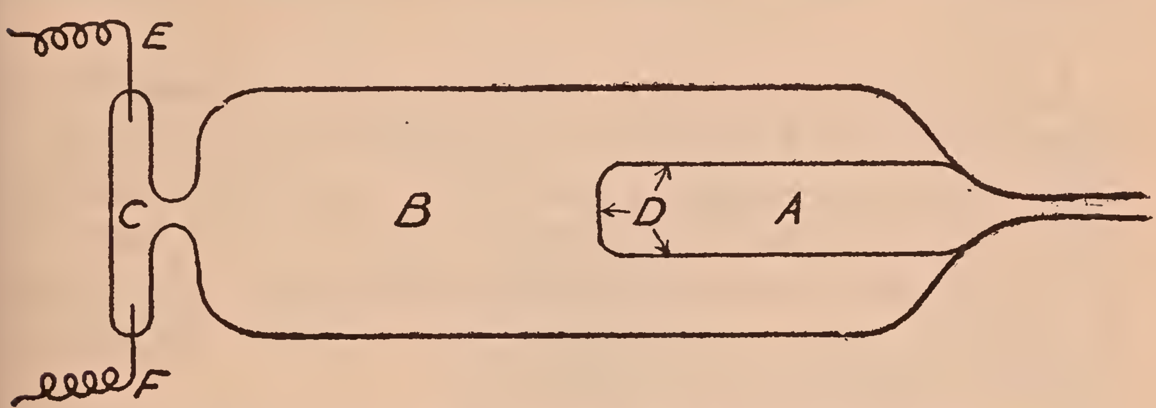

Fig. 12. Apparatus for Rutherford's Experiment.

shot through them too small for us to detect with a microscope.

If the solid bodies are full of small holes it proves the porous structure of solid bodies.

If the solid bodies can have tiny holes shot through them which we cannot find it proves that invisible things do exist and that when evidence of an invisible thing is found, its mere invisibility is no reason for disbelief.

Experiment 8.—A glass vessel of two compartments was made something like Fig. 12. The partition D between A and B was of thin glass. When A was filled with helium gas (the same gas as is now used for balloons) no helium could be detected in compartment B. Evidently the thin glass wall is solid or has holes too small for helium gas particles to get through.

But when A was filled with radium emanation, then in B was found helium gas. It seems as if the high power particles, that we know radium emanation shoots off, could pass through the fine spaces in the glass structure or punch a hole in the glass so small that when we cleanse the apparatus and again put helium in A we can find no trace of it passing through to B. The compartment C is really a part of B and is where the test for helium is applied by jumping a spark across the terminals E and F to see if we get the peculiar color of helium. This experiment was devised by Rutherford.

More About Atoms.—Scientists have proved from experiments on radio-active chemicals that the atoms of these materials explode, and shoot out alpha particles which have positive electrical charges in them and also beta particles which are negative electricity. Thus there is evidence of a core or nucleus in an atom made up of positive electricity, and electrons.

These are in a compact mass at the center of the atom. Surrounding this nucleus are revolving electrons (specks of negative electricity, all alike), and beyond these a few electrons hovering in about the same position all the time.

I have tried to give you an idea of atomic structure by the diagram of an atom of aluminum shown in Fig. 13. The proportions are wrong because the page is too small for the picture and I did not want to show you specks too small to be seen. However, you will get a correct impression of the cluster at the center composed of 26 protons and 13 electrons. Surrounding this is a shell of 13 electrons.

The Make-up of Electricity.—The electrons which make up one half of each piece of the materials of this world are tiny specks of electricity. But there are two kinds or characters of electricity, one we call positive, locked up in the nucleus of all the atoms of

this world, the other we call negative, which forms the outer shell of all the atoms of this world. To the positive specks we give the name of protons.

Definition of Electricity.—I really dislike to use such a cold-blooded word as definition, but amid

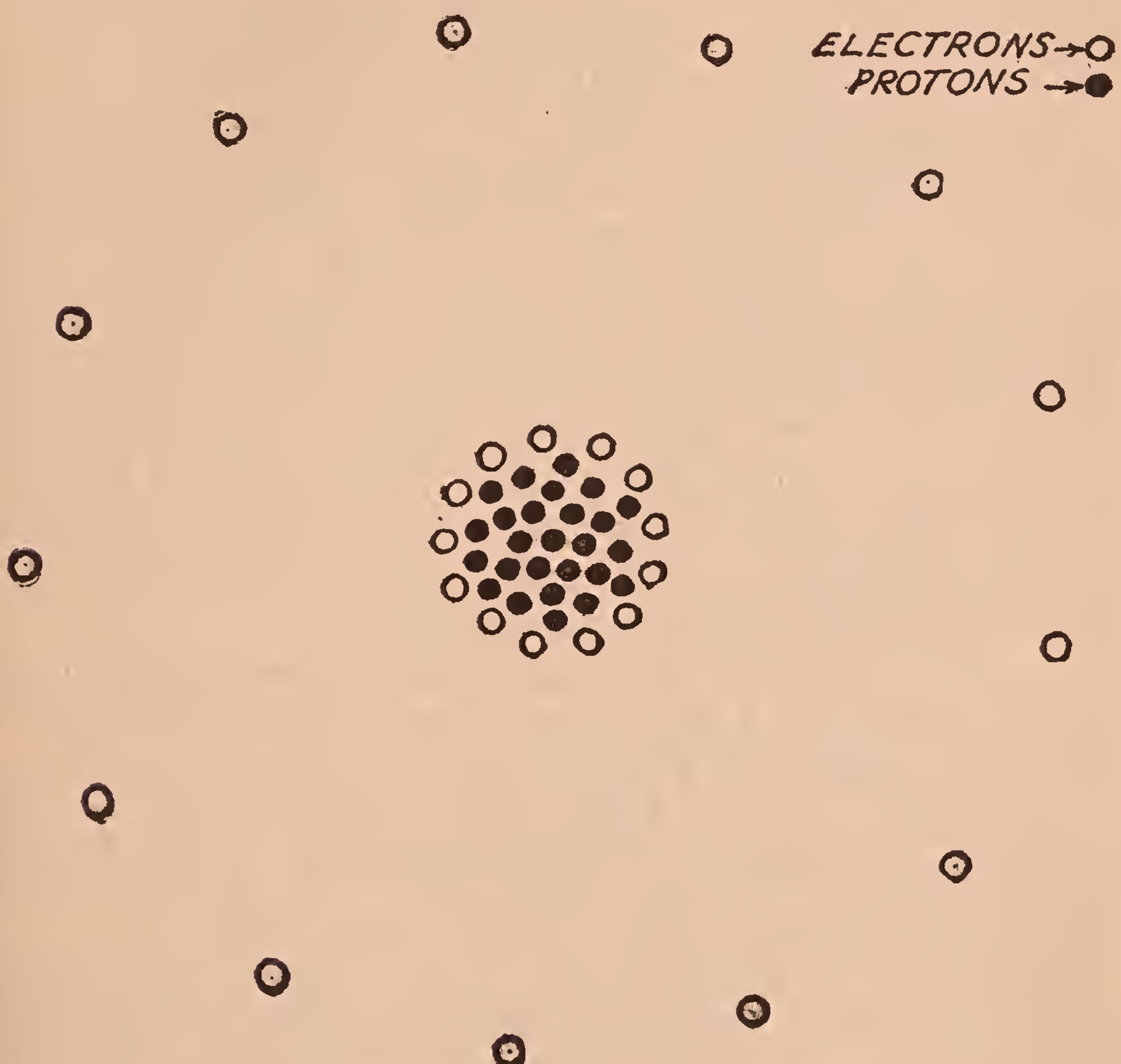

Fig. 13. A Diagram of an Atom of Aluminum.

the delightful ideas and imaginings about science, appears the absolute necessity once in a while of telling precisely about things. Defining or giving a definition is merely telling precisely. One should be able to take pleasure in so selecting words and arranging them that they give a clear and exact idea of what is being talked about.

What are we talking about? Electricity. Well then, we had better change the subject, because just plain electricity, the thing that makes materials what they are, is not what you meant when you asked, "What is electricity?" You wanted to know what electrical charges, currents of electricity, lightning discharges, and static electricity all are. In a moment I shall tell you. I shall now take a minute or two to tell what *electricity* is.

Electricity is the stuff that makes the materials of our world. It comes in little tiny pieces or specks, too small for us to even hope to see. These specks are of two kinds, each quite different, yet all the specks of one kind are exactly alike. One kind of speck is light and moves nine times as fast as the heavier ones, and the heavier ones are about 1850 times as heavy as the lighter ones. Each kind likes the other kind and they attract each other, but dislikes its own kind and they repel each other. The lighter specks are called electrons and the heavier ones protons.

PROTONS.—The heavy, slow-moving specks of one kind of electricity form two thirds of the nucleus or core of an atom of any material.

ELECTRONS.—The light, fast-moving specks of the other kind of electricity form one third of the nucleus or core of an atom, and all of its outer shell.

Friction, moving magnets near wires, and certain chemical actions result in a separation of electrons from the atoms. The separated electrons and the excess of protons on the atoms, which have been robbed of electrons, form what we call electrical charges.

Electrical Charges.—It may be a queer statement to make, but I am sure you will agree with me when I do make the statement that electricity is no good for anything electrical. Now, of course, you see what I mean. I mean that a bunch of those specks, half of one kind and half of the other kind, may be zinc or gold, may be some substance, but is not what you call elec-

tricity. The thing that gives electrical effects is a bunch of one kind of specks without there being as many of the other kind there.

Charged bodies have more of one kind of specks on them than of the other kind.

How to Get Charges.—You see now that to get an electrical charge you must separate the kinds of specks. When we wish to charge a body positively we must have more protons than electrons on that body. When a negative charge is wanted we must have more electrons than protons on the body or place.

Actual Methods Used.—Friction, cells, and dynamos are the ordinary ways in which charges are piled up at places, and each of these will be fully discussed in the different chapters of this book.

Different Kinds of Electricity.—People are all human beings, though some are calm and pleasant, others hot-headed and peppery in disposition. Some move steadily in one direction, others dash hither and thither.

The different methods of producing electrical charges will produce different effects, and so you hear people talking of static, current, and high frequency electricity, of a. c. and d. c. They talk of current, charges, juice. Suppose we take a little time now and see what all these terms mean. We shall then be able to talk about electricity to our friends, knowing that we are using the correct words to express our ideas.

When we say electricity we really mean a movement of electrons. When we say an electrical charge we mean too many or too few electrons at one spot.

Static Electricity.—When charges get on insulators, they accumulate and we have, on account of the non-conductivity of the surface of these materials, electrons at rest. For this reason we call them *static* charges, static electricity or simply "static," for static means "still."

The surface of conductors may be supplied with electrons so rapidly that they can not flow away. We then get a pile of electrons and static phenomena are seen even on conductors.

Static.—In the air there are charges of electricity. These charges are picked up by our antennas, and these charges are conducted into our radio receivers. They were bunches of electrons in the air, and they slide down our antennas like naughty youngsters down a bannister. They come into our sets in bunches and, "slam bang," they knock the noises into our 'phones.

CURRENT ELECTRICITY.—A stream of electrons passing along a metal or a liquid conductor is called a current. This is the method by which electrons are pushed into our homes and shoved along to our lamps, vacuum cleaners, toasters, irons, and such like.

Juice—When quite familiar with electricity and the things it does, we like to refer to current electricity as "juice."

THEIR DIFFERENCES.—To me the behavior of static electricity seems to indicate that at a certain spot there is an enormous number of electrons and somewhere near them an equal deficiency of electrons. The place where there is an excess of electrons has certain properties which we call "having a negative charge." The place where there is a deficiency of electrons has similar, yet different properties, and we say that this place "has a positive charge."

The attraction between these positive and negative charges is very great. Only a very poor conducting path can keep them apart. When these charges accumulate the strain between them is overwhelming. Then the electrons rush with lightning speed towards the place that is positively charged.

The force that they exert in this rush is tremendous. The electrons bounce off, surge and sway back and forth, until all becomes calm and neutral, giving us a

quiet time in which to see if results have been beneficial or injurious.

Wherever a condenser is used in an electrical apparatus, we are holding small static charges for some useful purpose. With large charges holes may be punched in glass, mica and rubber insulation thus letting the electrons run wild and do damage. Trees may be split, houses wrecked and valuable electrical apparatus changed into a combination of junk and a bad smell.

Current electricity appears to me to be a steady stream of electrons pushed from behind by electrical pressure, this pressure merely pushing, without directing. It says to the electrons "Get out," and they go. They go mainly by the path of least resistance, and thus it is that the copper wire has a current of electrons flowing through it. The steadiness of the stream makes current electricity useful for continuous operations. The moderate quantity of electrons is made up for by the continual supply of them and the moderate pressure behind them makes it easy to guide them in the path that we have decided that we want them to go.

By offering copper wires for them to slide along or through and placing rubber, porcelain or mica in their way in other directions, we lead electrons like a pup on a string.

Direct Current.—The stream of electrons from a cell moves in one direction. This would be called a direct current and is suitable for practically every electrical purpose. It is especially suitable for electroplating and electro refining of metals. It is not suitable for use where the pressure must be automatically changed.

Alternating Current.—If you think of an electric iron or toaster as being heated by the friction of the electrons crowding through its wire, you will realize that these electrons could move in either direction or both directions and give a similar result.

Dynamos, magnetos and all generators of electrical pressure using magnets, are push and pull devices that reverse their push at regular intervals. They all drive the electrons one way for a fraction of a second and then reverse their pressure and drive the electrons the other way. This kind of stream of electrons is called an alternating current.

It is suitable for heating, lighting, motors and where automatic changes in pressure are necessary.

Cycles.—Suppose you lived in the middle of a block and left the house to walk to the corner to post a letter. Arriving at the corner you find that the box has been removed. You walk back to the other corner, passing your house on the way. You post the letter and go home.

You have reversed the direction of your walking twice and have made what an electrician calls one cycle. You did not complete the cycle until you arrived in front of your house facing in the same direction as before. When you passed on your way back to the other corner you had only completed half a cycle.

Frequency.—In alternating current we speak of the number of cycles per second as the frequency. The number of times an electron reverses its direction is twice the number of cycles per second. To say it differently, half the number of reversals per second is the frequency.

Low Frequency.—All the a. c. supplied to your home or to factories is of low frequency, there being 66 to 133 cycles per second.

High Frequency.—Under this name the frequencies of 30,000 to 1,500,000 are grouped.

Radio Frequency.—The frequency of the current entering your radio receiving set is about 800,000. It is called radio frequency to distinguish it from a frequency that can cause a telephone to make a sound.

Audio Frequency.—The frequencies that are audible

(hearable) range from 16 to 5000. Above or below these frequencies many ears will not respond. If a current of radio frequency passed through a telephone it would hesitate instead of vibrate.

Music consists of vibrations at frequencies from 100 to 3000, speech contains frequencies from 200 to 2000. Because all these are audible we call them *audio frequencies.*

Electricity Known by Its Effects.—All these different styles of electrical charges and currents do different things in different ways, or sometimes the same things but in different ways. Some of these forms of electrical energy are worthless for one job, but just the thing for another piece of work. We must therefore learn about them all. You now know the names of the forms of electricity and have a rough idea of what they are like. We will proceed then, to take up where our electrical energy comes from, how it reaches us, and how we harness it to do our will, what precautions we must take to prevent it from getting loose and doing damage, and at the same time study why it does the things that we find it doing.

CHAPTER IV

WHERE ELECTRICITY COMES FROM

Nature's Storehouse
- We Create Nothing
- Nothing is Destroyed

Energy
- Potential Energy
- Kinetic Energy

The Other Half of Our World
- Quanta

Borrowing From Peter to Pay Paul

Where Electricity Comes From

Separation of Electrons and Protons
- A Little Argument
- Isotopes

Static Charges
- Experiment 9
- Experiment 10

Static Everywhere

Atmospheric Electricity
- Franklin's Kite
- Franklin's Statement
- Thunder Storms

Lightning
- Lightning Rods
- Wireless Antennas

CHAPTER IV

WHERE ELECTRICITY COMES FROM

Nature's Storehouse.—We have already come to the conclusion that the whole world is made of electricity, so why bother about where it comes from? True, but we are again running into our old trouble, that when we say electricity we do not really mean just electricity, but have in our minds electrical charges and currents.

Yet after all, when we wonder where the electrons which light our homes, toast our bread and refine our copper come from, the answer that they have come from the electric light station is not going back far enough. The supply of electrons in this world is limited and definite. If all the specks that make the materials of this world were counted just half of them would be electrons.

Of course we cannot count them; there are too many in the world to be counted, yet their number is as definite as if we had them all tagged and counted.

These electrons in Nature's storehouse are the source of all charges, and currents of electricity. We catch them, shove them, push them into crowds, pile them up on places where they cannot jump off as fast as they arrive; we jostle them along, all at high pressure and marvelous speed.

We Create Nothing.—We do not manufacture electrons. There are the same number in the world today as there have always been, and there will be the same number years from now. All the changes from copper ore to copper, from zinc to zinc sulphate, from

radium to lead merely change the places where the electrons and protons live. The electrons and protons are not destroyed, nor are they altered in the tiniest degree. They are eternal and unalterable.

Nothing Is Destroyed.—The electrons and protons form other groups, and the materials will in consequence be known to us by different names.

We must remember then, that in obtaining electrical charges or currents, we create nothing, we destroy nothing, but we simply change things, and during this change we move a bunch of electrons from one place to another. To do this requires energy.

Energy.—The ability to do work is called energy. Energy is given out when bodies cool off, when electrons fall nearer the nucleus and revolve in smaller orbits, when bodies fall towards the earth. Energy is stored up when a body or set of bodies is under restraint and would do something if the restraining force were removed. Wound up springs, a stick of dynamite, a suspended weight, or a bunch of electrons fenced in by paraffined paper are examples of stored energy.

Potential Energy.—When energy is stored up in a body or set of bodies ready to do work when the restraining force is removed it is called potential energy.

Kinetic Energy.—When the ability to do work is due to the motion of bodies it is called kinetic energy.

The Other Half of Our World.—We are now able to clearly understand that a world could be made of matter, (specks of electricity), and that this world would work—or had I better say operate?—if it contained energy (ability to do work). A moment's thought will convince you that all we do in this world is to push and pull matter (electricity) around, using up energy to do it.

So our world, reduced to the simplest parts or elements, is composed of three things: protons, electrons, and energy.

QUANTA.—Rather mean to spring this word so suddenly. I did not intend to do so, but it slipped right off the pen. It came in so naturally, because a quantum is only the bit of energy that we use for a measure when we are considering the small quantities of energy which are radiated from atoms. Quanta is the proper plural rather than quantums.

Borrowing From Peter to Pay Paul.—In about two minutes I intend to perform an experiment in which I shall collect a lot of electrons at one spot. Where shall I get the energy to do this? Shall I get it from the muscles of my right arm? Yes, but could I use my arm vigorously had not the cook fed me well? I'll tell my readers, No. So as we trace back I find that I get my energy from the sunshine that furnished the energy to warm and water the plants that made my food.

It took us some time to discover that the work of the world is operated by borrowed energy. However, that is always the case. We neither create nor destroy matter (electrons and protons), and we neither create nor destroy energy. We only transform energy from one kind to another, making it operate our machines, and do our work as it changes.

If you will turn to the Frontispiece in this book you will see that I have shown you how the sun hidden behind the clouds is the place where the light given by your electric lamp came from.

Where Electricity Comes From.—The sun raises the water, which later on comes down as rain into the mountain lake. From the dam through the flume or penstock, the water runs down to the power house. There, flowing through the turbine it turns the large dynamo or generator. The stream of electrons at high pressure is guided by the transmission line in the form of a high voltage, alternating current, across the river and country to a sub-station. Here transformers re-

duce the pressure low enough so that it is safe to carry it under ground through the suburban streets to the home of Mr. Elmer. In front of the garage there is an electric lamp, the tungsten wires of which are made white hot by the electrons rushing through them. Thus you will see that the lamp is operated by the energy of the sun.

Perhaps the boy who is reading this lives where mountain lakes or rivers capable of being dammed are scarce. Then you are getting your electric light from the sun just the same, only the details of the process differ.

Years ago the sun poured its energy in the form of heat on the forests; it used its ability to work in lifting water up, to fall later as rain, upon the trees, and thus wood was formed. When the wood of this luxuriant forest was covered with water, mud or dirt, before it could decay, it was turned into coal. The sun's energy, locked up in this coal, is released in the furnace under the boiler, and carried by the steam into an engine. There the energy revolves a dynamo and we get a stream of electrons.

Separation of Electrons and Protons.—In order to produce an electrical charge we may rub together two different substances. Some convenient ones would be: your comb and your hair in dry weather, your dry hand and the family cat's furry back, a glass rod and a really truthfully silk necktie (that came from a silk worm), also a flannel shirt or wool trousers. Suppose we use the glass rod and the silk. The thin glass rod furnished in chemical sets is not as good as a test tube. If the test tube is very short you may find that most of the charge escapes through your hand and body to the ground. If you can buy a cheap towel rack, whose rod is glass—either the transparent or milky glass will do—you have a proper glass rod. It will be long enough to hold and rub conveniently, and the part not

in contact with your hand will be large enough to hold a good sized charge.

Now that you have your glass rod and piece of silk cloth ready for the experiment, please lay them aside a moment and do a little mental work.

Think hard for a moment of the idea that these two materials are nothing but an enormous number of little pieces. When these are rubbed together the pieces at the surface are going to get mixed up. Also remember that an electron is only happy near a proton, but that any old proton will do. You can then understand that when by the rubbing you have gotten the two surfaces well mixed, perhaps on separating them you might take away some of the electrons from the glass because they adhere to the silk.

A Little Argument.—Wow! Hold on! Wait a bit! Give the poor author a chance to explain. I only said perhaps. But I'll tell you right to your face, that I am only waiting for the storm of protest to calm down, when I will tell you that this is what really does happen.

I can hear the protest, that it could not happen, for if it did, then the surface of the glass would be changed. If glass is a mixture of protons, electrons and energy, then when you take away some electrons you have a new substance. Quite right, you do.

Furthermore, possibly you are saying that those extra electrons are not merely smeared on the surface of the silk, but that the rubbing must have rubbed them in so as to form a coating of a new material on the silk. Well, you might say so. I am not so sure of this, because electrons can and do exist by themselves, and so unless they actually are forced into the atoms which make up the silk there will be no new substance.

But to return to the glass. When some of the electrons are torn away from a few of the atoms which make up the glass, we get a few particles of a new

substance, but a quantity too small to see and of a kind not possible to detect by chemistry.

Worse and worse! Not content with all the other bunk, he is now trying to tell us of a substance that the chemists, the modern wizards, can't detect. Yes, I am telling you that. Ask any chemist, and he will tell you that this is true, and also of the

Isotopes.—There are two kinds of chlorine, two kinds each of bromine, potassium magnesium, lithium, silicon, and six kinds of lead. These are different to the physicist or electrical investigator, but absolutely the same to the chemist. He can't tell them apart, simply because chemically they are the same.

Substances that are chemically indistinguishable yet really different in their internal structure are called *Isotopes.*

It may be possible, then, for you to rub electrons off the glass on to the silk and yet have the substance show no difference to you or to the chemist, while to the electrical man they *are* different, for the glass is charged positively and the silk is negatively charged.

Well, let's do it.

Static Charges.—*Experiment* 9.—Bend a piece of wire into a hook at one end and fasten it into a hole in a block of wood so as to form a support. Tie a small piece of tissue paper by a silk thread to the hook. Warm a glass rod and a piece of silk and rub together vigorously. Bring the glass rod *near* the piece of tissue paper and it will be attracted. Perhaps we should say that there is a mutual attraction between them.

You electrified or charged the rod by the rubbing, in the way previously explained, but the tissue paper had not been rubbed and was therefore neutral. What then has really happened? It must be that the excess of protons on the glass rod attracts an equal number of

electrons over to the part of the paper nearer the rod, thus charging that spot negatively and making the further side positively charged.

Then between the excess of protons on the glass rod and the excess of electrons on the nearer side of the paper there is an attraction. This shows that UNLIKE CHARGES ATTRACT EACH OTHER.

Experiment 10.—Perhaps you have already in Experiment 9 permitted the tissue paper to touch the rod. If not rub silk and rod again, and holding the rod near the paper as the paper is attracted let it touch the rod. It sticks for a moment and then is repelled.

The charged paper and charged rod afford a path for the excess electrons on the part of the paper near the rod to get back to the glass rod. Since the glass rod was heavily charged positively, and the paper only had a weak negative charge, the electrons coming over from the paper did not make the glass rod neutral. The positively charged glass rod and the positively charged paper now repel each other. The whole discussion may be followed step by step by going over the parts of Fig. 14.

Have you noticed that in these experiments I did not tell you to use the silk with which you rubbed the glass? Had you tried to get an effect from the silk you would have obtained little or no results. Surely the silk was charged. Why then did it not show a charge? Just try the experiment again. Notice that the silk was all crumpled up and a great deal of its surface was in a very good contact with your hand. Thus the silk was kept neutral by the surplus of electrons flowing away through your body.

Suppose you rub a fountain pen on your woolen trousers while the trousers are on your body. Both trousers and pen will become charged. The charge on

the end of the pen that you are not touching will stay there, for the hard rubber of the pen is not a conductor, but your trousers cannot be permanently charged. They are connected quite well to your body, which is a good

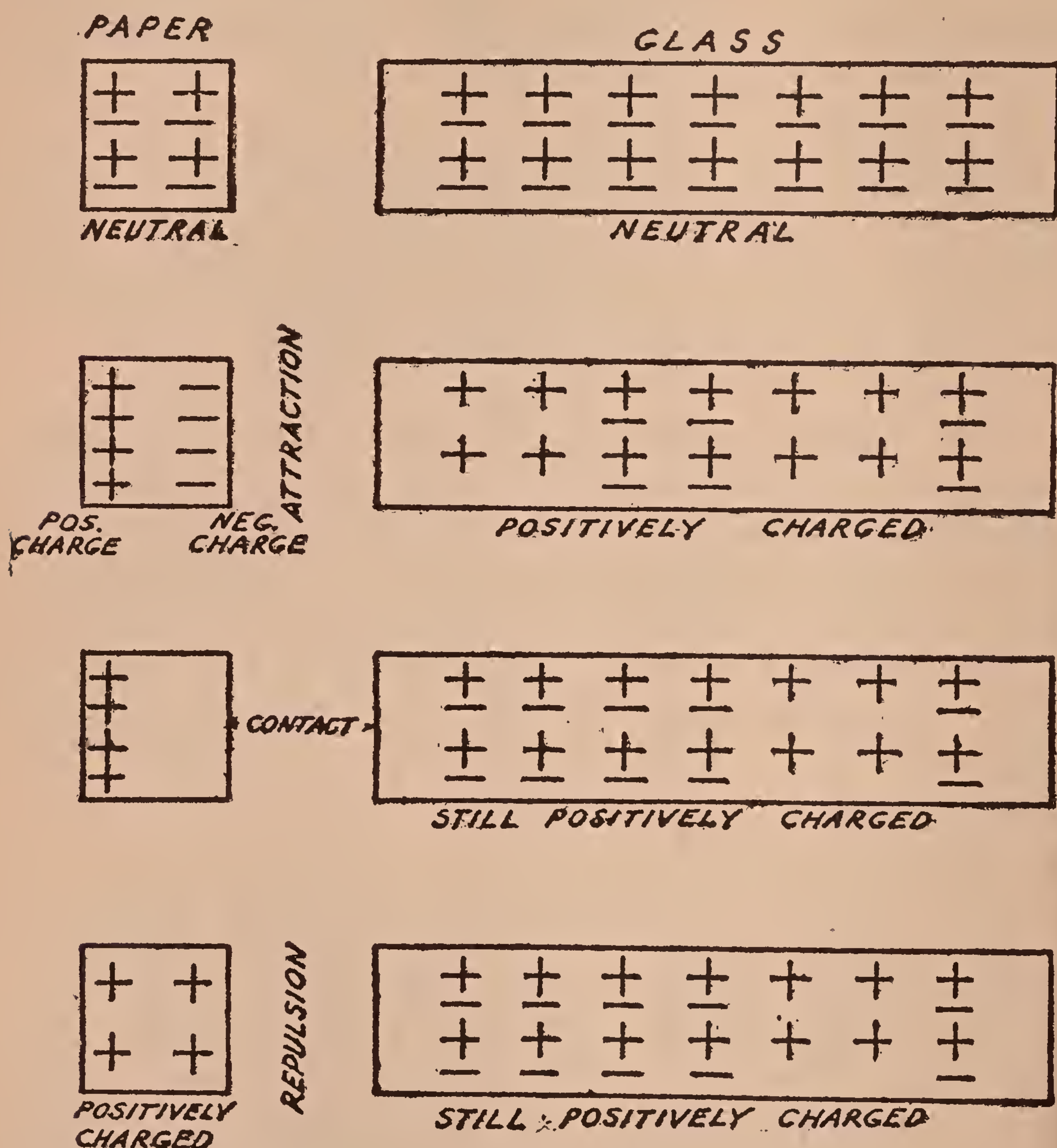

FIG. 14. WHY THE PAPER IS ATTRACTED AND THEN REPELLED.

conductor, and so electrons can flow into the woolen trousers, thus supplying its deficiency of electrons which the rubbing had produced.

STATIC EVERYWHERE.—Static charges are developed in many places. Friction is usually the cause of their

formation. Sliding your feet over woolen carpets, the sliding of my hand over the paper as I write, both produce static charges. When I make an error and erase, then the vigorous rubbing produces such a charge on the paper that the whole sheet will stick to my hand when I attempt to lay it on the pile of finished sheets. I find more charge is generated when I brush off the crumbs of paper at the end of the erasing than was produced by the actual rubbing with the eraser.

Tearing a sheet of paper from a pad, if done quickly, will charge the sheet torn off and the pad.

In factories the belts on the pulleys of rapidly revolving shafts create very heavy static charges.

A locomotive when blowing off steam through the safety valve electrifies the drops of water in the cloud of condensed steam.

Atmospheric Electricity.—The similarity in the effects of lightning and those of the electric spark obtained from a static charge was noticed by the earliest investigators.

Lightning punches holes through things opposing its passage, and where they are combustible, often sets fire to them. It can produce all the effects of heat in melting metals and turning them into vapor, leaving behind an odor of ozone. This odor may be observed when any electrical device that causes sparking has been in operation for a few minutes.

To Franklin is given the credit of showing that all the stunts done by lightning were also done, although in a much less degree, by static charges. He did this by sending up a kite.

Franklin's Kite.—In June, 1752, Benjamin Franklin raised a silk kite carrying a sharp pointed wire about a foot long. He held the kite string by a silk ribbon, and to keep the ribbon dry stood within a doorway. To the end of the kite string was attached a metal key, probably the key of the door beside him.

He and his son watched with great interest and were feeling that after all nothing was going to happen. Finally the kite string becoming wet, and hence a conductor for the electrical charges, they saw the frayed portions of the string stand out straight. When Franklin's knuckle was placed against the key a big spark occurred. Leyden jars were charged, lots of later experiments done, and finally he found that sometimes he was collecting positive charges while at other times negative charges. Thus he showed that lightning and static electricity are the same.

Franklin's Statement.—To quote his own words: "Lightning and the spark from excited electrics are the same on account of giving light; color of the light; crooked direction; swift motion; being conducted by metals; noise in exploding; conductivity in water and ice; rending imperfect conductors; destroying animals; melting metals; firing inflammable substances; sulphurous smell (he meant smell of ozone); similarity of appearance between the brush discharge from the tips of masts and spars sometimes seen at sea, called St. Elmo's fire by the sailors, and the slow escape from points on an electrical machine or a Leyden jar." I'll tell the world that old Benjamin was some careful and accurate scientific observer.

Thunder Storms.—One of the most interesting things that is due to atmospheric charges is the thunder storm with its rain, lightning and noise. Each particle of water in the cloud seems to have acquired a charge when it hopped out of the body of water in which it lived on the earth's surface. This charge is probably a small one.

As these particles of water way up in the sky fall towards the earth, many touch others and unite, so that the charges of say eight small drops may now be on one drop weighing eight times as much as a single drop but not having eight times the surface of a single

drop. The surface of the large drop is only one half as large as that of the eight little ones.

The charge can only be on the surface, so the eight charges are squeezed into half the space and so the pressure is doubled.

By the repeated union of these larger drops, the pressure becomes very high. Also the influence of

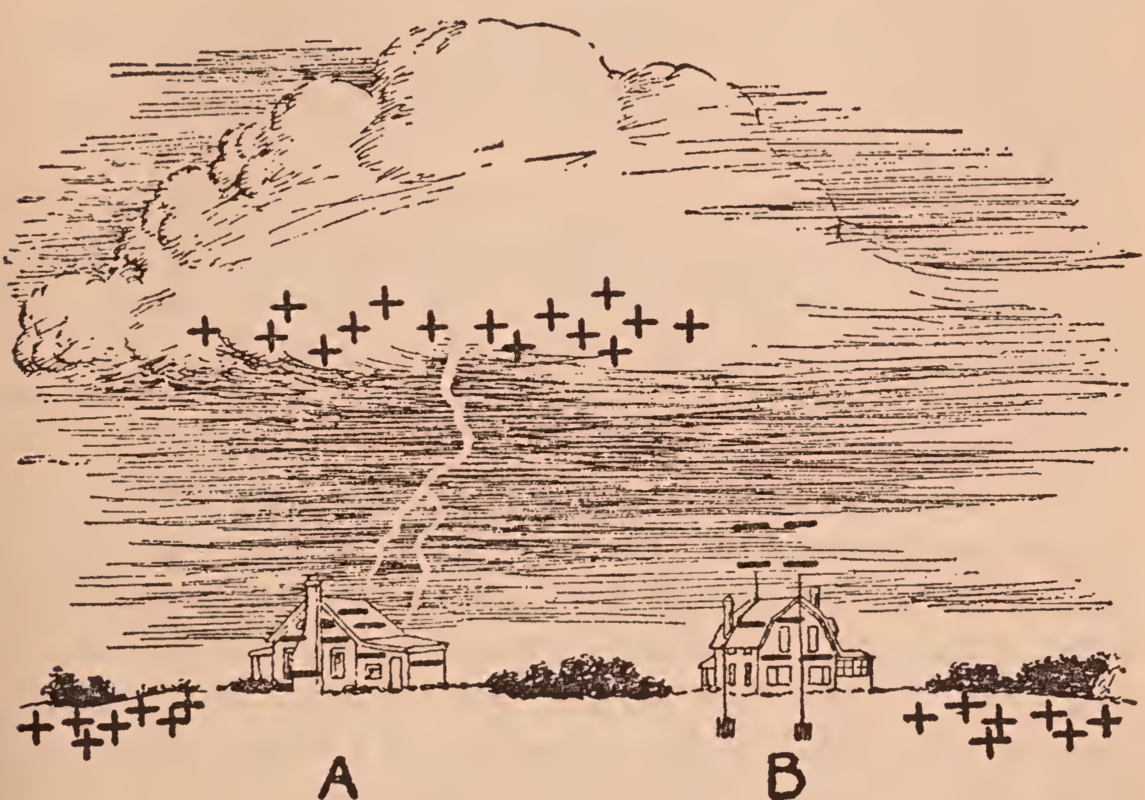

Fig. 15. A Thunder Storm.

the charged cloud is to accumulate a charge of the opposite kind of electricity on the earth beneath the cloud.

Lightning.—As you will see in Fig. 15, Mr. Allison's house at A is highly charged with negative electricity, and the positive charge forms on the ground as a ring around the negative. There is danger in that accumulation of + and — charges, and if the pressure to discharge through the air is greater than the electrical resistance of the air, a lightning stroke will hit Mr. Allison's house.

Lightning Rods.—Sharp points will discharge the places to which they are attached. Mr. Barrow's home at B is protected by properly applied lightning rods. The sharp points at the top of these rods are continually allowing the negative charges on the house to slip off into the air. These rods are connected to metallic plates buried in the ground and so the ground about the house is discharged.

All this tends to discharge the house and to neutralize the parts of the clouds above the house. No charge, no lightning stroke.

Wireless Antennas.—The aerials or antennas of wireless receiving and sending sets are really a protection against lightning strokes. The narrow wires of which they are composed will tend to dissipate and discharge any electrical charge that a cloud is trying to accumulate.

The antennas had better be permanently grounded by one of the vacuum devices that permits the reception of the radio frequency current, yet always offers a nice easy path from the ground to the air for static charges. In the rare event that charges accumulate more rapidly than your antenna can get rid of them, when the lightning hits it finds a path to go harmlessly to the ground.

CHAPTER V

BEHAVIOR OF ELECTRICAL CHARGES

- Distribution of Static Charges
  - Charges Always on Surface
    - Experiment 11
- Testing for Charges
  - The Electroscope
    - Experiment 12
- The Construction of an Electroscope
  - Method of Charging
  - Making a Test
  - The Rule for a Test
- How to Make an Electrophorus
  - Experiment 13
- Something for Nothing
- The Leyden Jar
  - Its Construction
  - Experiment 14
    - Its Operation
- Where Does the Charge Reside
  - Experiment 15
- An Explanation with Apologies
- Condensers
  - An Experimental Condenser
  - Experiment 16
    - Capacity of a Condenser
    - The Microfarad
- Building a Condenser
  - Experiment 17
  - Rule for Capacity of a Condenser
    - Dielectrics
- Condensers Connected in Circuits
  - In Parallel
  - In Series
- A Bit of History

CHAPTER V

BEHAVIOR OF ELECTRICAL CHARGES

Distribution of Static Charges.—When a body is charged, we should not say that it is full of electricity; covered would be a better word to use. When electrons are piled up on a solid ball of conducting material so that it is heavily charged you have covered the surface only. For this reason a hollow ball of metal, a solid metal ball or a wooden ball covered with tin foil will all hold the same amount of electrical charge.

When the object charged has corners, edges, or points, the electrons are not evenly distributed over the outside surface, but as shown in Fig 16, the charge is greatest at the corners, or edges. The sharper the edge, the heavier is the charge there, and at a point, we have such a piling up of electrons that some are jostled off the body. Just imagine a large jagged rock in a field and a crowd of boys crazy to get on that rock. They pile on it two or three deep with the result that many are shoved off.

If upon a ball charged with electrons a tack is placed point upwards, the ball will be discharged by the electrons sliding off this point into the air.

Not only does an electrical charge collect on the outside of a body, but if the inside is made the outside, the charge will shift. At A in Fig. 16 is shown a device that will give you much fun and enable you to fool your friends.

Charges are Always on the Surface.—*Experiment* 11.—Following the idea of Fig. 16A, make a

wire ring and support of heavy wire. Secure this to a wooden base block. Give the base a coat of shellac.

A bag of thin silk cloth, made in a cone shape, is sewed or glued to this frame. A silk thread runs from the point of the bag both ways. By holding this

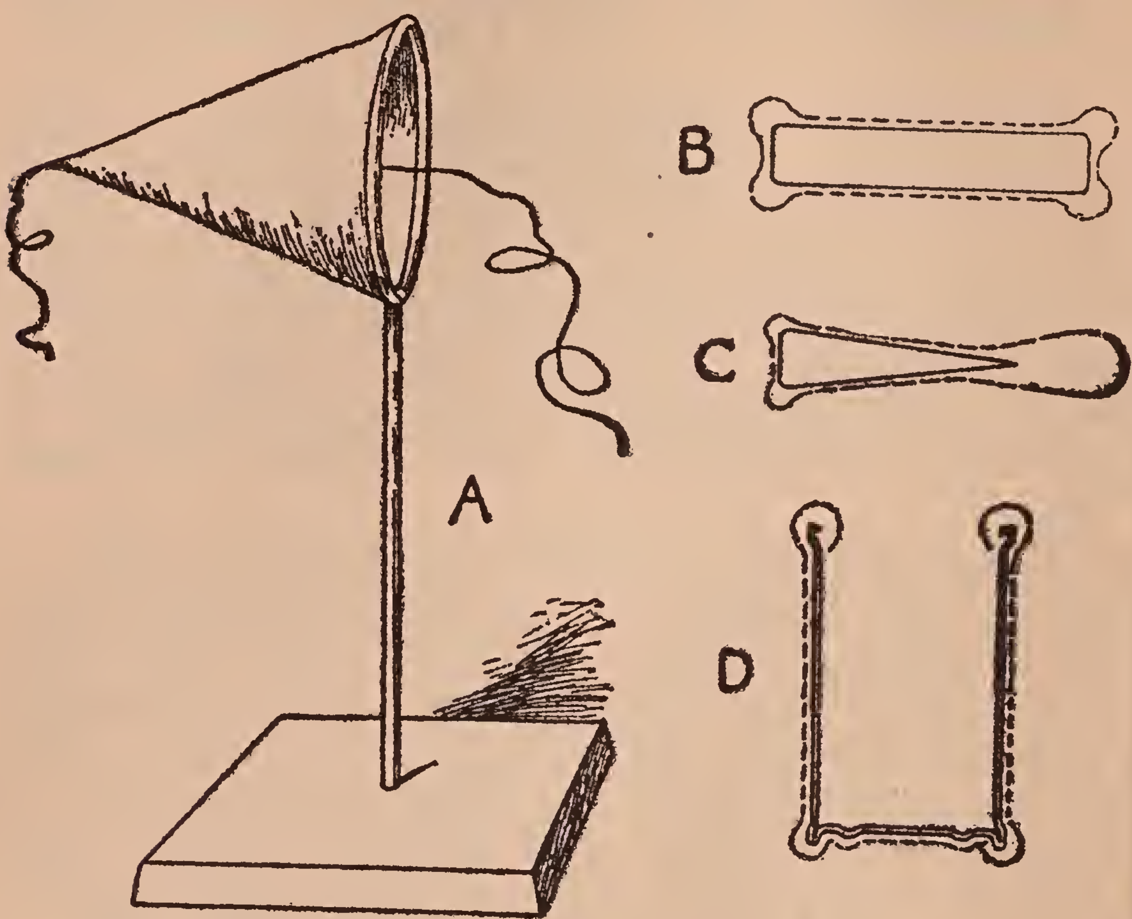

FIG. 16. DISTRIBUTION OF STATIC CHARGES.

string taut you can pull the bag inside out without letting it fall.

Rub the bag with a glass rod and test the outside and inside for charge. There is charge only on the outside. By means of the silk thread turn the bag inside out and testing again you will find the charge only on the outside.

The very best silk for this bag is taffeta, for the kind of cloth called silk taffeta has a great deal of the metal tin in its fibers. As you can imagine, this

tin makes a conducting path from the inside to the outside. Since I can imagine your mother's feelings if you should tell her about the tin and silk cloth, perhaps it would be wise to keep silent.

Make tests at different places, especially at the point to find out the distribution of the charge.

Testing for Charges.—To pick up charges we need a *proof plane.* This device with the high-sounding title is such a humble little thing that you can make one in a jiffy.

On a circular piece of thin metal or heavy tin foil put a drop of glue or shellac and when nearly dry stick a glass rod into the drop. When dry, a little more of the adhesive will reinforce the joint. This sounds simple, is simple and always works when I do it. Since some of my boy friends tell me that it never works, and that the metal always breaks off at the slightest touch, I will give you another method.

Coil a short piece of wire into a tight coil or helix, which is the technical name for it. Solder this coil at one end to the metal disk and thrust the glass rod into the coil. It may be knocked off the rod by rough treatment but it may be replaced in a jiffy.

With the proof plane you may pick up a sample of any charge and bring it over to an electroscope in order to determine whether it is positive or negative.

Remember that a positive charge is when electrons have been taken away from the atoms of the material. Negative charge is developed when electrons have been added to the atoms.

The Electroscope.—The old standard device used years ago to detect the presence of electrical charge and to determine its positive or negative character is still in use today. The most eminent scientists use it for some of their experiments on radio-activity and the internal construction of matter.

THE CONSTRUCTION AND OPERATION OF AN ELECTROSCOPE.—*Experiment* 12.—Select a wide-mouthed bottle. Find a cork or rubber stopper to fit it, or make one of wood. With the gimlet, drill a hole through the cork and select a piece of heavy wire of sufficient length to make the support for the leaf. See Fig. 17.

Cut with the tin snips or metal shears a circle of any metal thick enough to hold its shape and yet thin enough for you to cut. Sheet tin is all right. This circle may be about two inches in diameter; a little more or less makes no difference. File the edges smooth.

Bend the wire over for about a half inch in a square hook and solder the short bent-over portion to the center of the metal disc. Thrust the wire through the cork and if it fits loosely plug tightly in the hole with pieces of match stick.

Pour melted paraffin over the cork until it is completely coated and the hole where the wire goes through is air-tight. Place the bottle on a radiator or near a register to get it warm and hence dry. Cut a piece of tin foil, aluminum foil or gold leaf about ½ inch wide and 3 inches long.

Clean the lower end of the wire, and bend with clean pliers to a hook. Put just two tiny dabs of shellac on the hook. Fold over the metal foil and hang on the hook. Place carefully in the warm dry jar, push the cork down firmly and the electroscope is finished.

The cheaper the gold leaf, the easier it is to handle, because there is more copper in it and it is not beaten so thin. Gold leaf must be held between sheets of paper when cut. Very thin aluminum or tin foil is much easier to handle and makes a sturdier, though less sensitive electroscope. The heavier the leaves, the more charge is needed to move them.

Charging the Electroscope.—Most measuring or detecting instruments are ready for use when they leave the maker's hands, but an electroscope must be prepared for use, or as we say, *charged*.

When your electroscope was finished it was in the neutral, uncharged, or discharged condition. All these words mean the same thing. Every atom of the metal

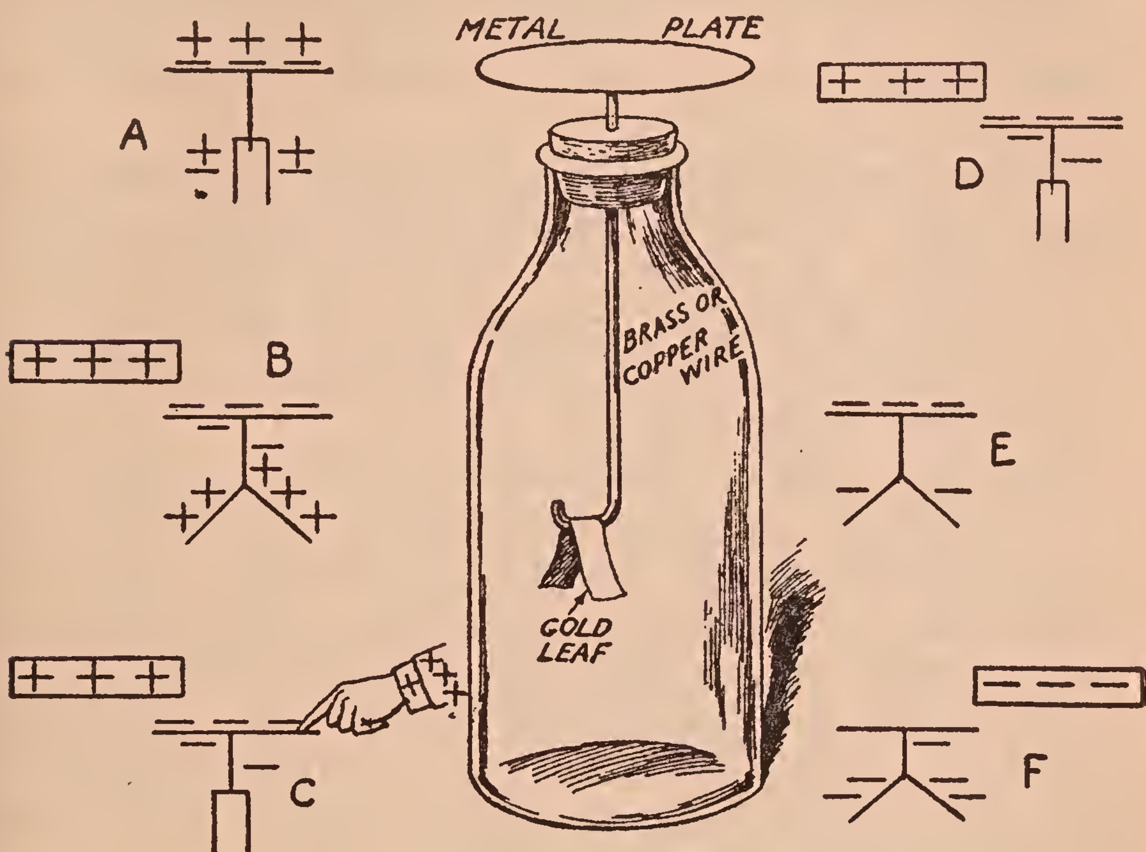

FIG. 17. THE ELECTROSCOPE AND HOW IT WORKS.

plate, wire and gold leaves was in its normal condition, which is the same as saying that each atom had its proper number of electrons; no more, no less than the exact proper number.

Take your glass rod and rub on the silk. It will become charged positively. In a diagram such as is shown in Fig. 17A, the combination + and — sign means neutral. To show that the glass rod is positively charged in the B part of Fig. 17, we mark it with + signs.

When the positively charged glass rod with its lack of electrons and excess of protons is brought near the electroscope, it attracts electrons from the gold leaves up to the metal plate. The distance from the metal plate to the glass rod is too great for the electrons to jump, or to put it another way the pressure needed to make them jump the space is much greater than the pressure that the glass rod can exert. The result is as shown in Fig. 17B. The gold leaves repel each other and separate because both are charged with the same kind of charge.

Keeping everything as it is, you must now touch the metal plate of the electroscope with your free hand. The negative charge on the plate is not affected for it is held by the positive charge of the glass rod. A charge held in this way by the influence of another is often called a *bound* charge.

Electrons will be taken from your hand and these will neutralize the positive charge on the gold leaves making them neutral. They then no longer repel each other and so fall down or *collapse*. The electrons leaving your hand temporarily make it positive. All this is shown in C of Fig. 17. Take your hand away and nothing happens, nor should anything happen because the electrical state of affairs in C are not altered when hand is removed as shown in D.

Remove the charged glass rod and the negative charge in the plate, being no longer held *bound*, is *free* to flow all over the surface of the metal plate, gold leaves, and the connecting wire. The gold leaves being similarly charged now repel each other and separate. See Fig. 17 E.

From the influence of a positive charge, the electroscope is now negatively charged. This process of charging without contact with the charged body is *charging by induction*. The charge on the electroscope is an induced charge.

Making the Test.—Rub a stick of sealing wax upon woolen cloth. Bring the sealing wax near the metal plate of the charged electroscope. Do not touch the metal plate with hand or sealing wax. The gold leaves of the electroscope will separate further because like charges repel and the sealing wax carried a negative charge which drove more negative charge down into the plates. See Fig. 17F.

The Rule for a Test.—When the leaves diverge further the tested charge is the same kind as that on the electroscope. When the leaves collapse the tested charge is of the opposite kind to that on the electroscope.

How to Make An Electrophorus.—You can easily make a device with which you may produce good-sized sparks. As shown in Fig. 18, get two tin pie plates, one a little smaller than the other, a small bottle for a handle, a wood screw and piece of wood.

Whittle the wood into a plug that will fit the neck of the bottle snugly. Solder the wood screw to the smaller pie plate; screw on the wooden plug. Push the bottle down firmly on the plug. The upper part is now finished.

In the bottom pan we are to form a cake of sealing wax. If you can purchase the big one-pound sticks of sealing wax, you had better do so. Melt the wax in a small pan placed in a larger pan of water. Thus you will avoid burning the wax. When liquid pour into your pie pan and place it on a level surface to cool.

The composition for your bottom pan may be made of a mixture of 6 ounces each of gum shellac and rosin, and 6 fluid ounces of turpentine. Melt the gum shellac in a double boiler, or pan in hot water. Turn out the fire. Stir the turpentine in. Light fire and turn very low. Add the lumps of rosin. Stir very gently until well mixed. Pour into the pie pan and set aside to cool. Unless you have done chemical experiments, and

so know how to handle hot things you should get some grown person to supervise the melting of the mixture.

Experiment 13.—To produce an electrical charge warm the pan and cover, to drive off all moisture. Rub the resin cake with a piece of warm dry flannel, or any fur you can procure. The resin cake will become negatively charged. Holding the top part or cover as it is

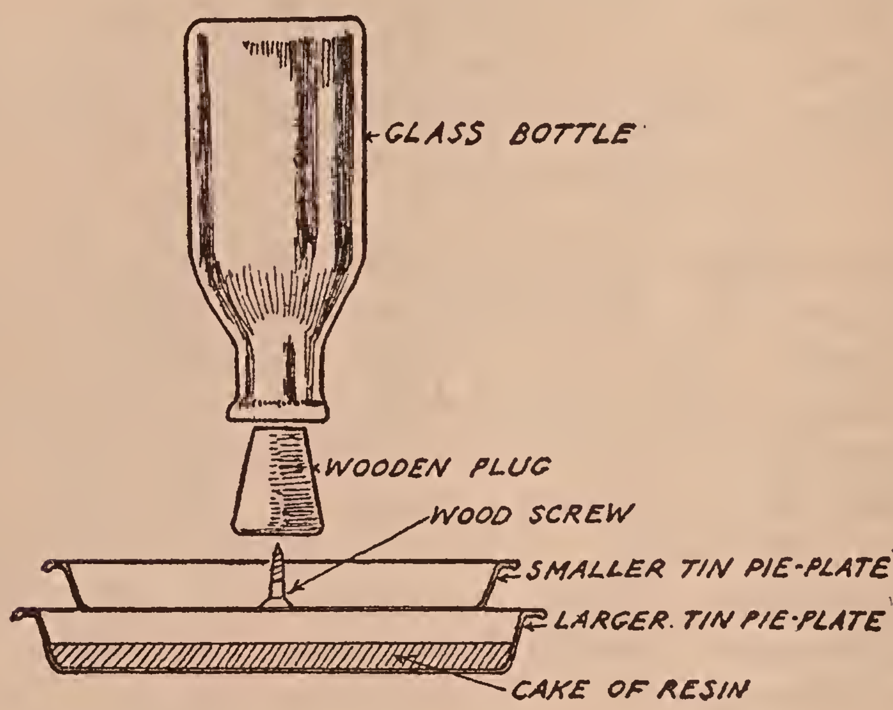

FIG. 18. THE ELECTROPHORUS.

called by its glass bottle insulating handle, place it on the resin cake. The influence of the negative charge of the resin cake charges the bottom of the cover positively and the top of the cover negatively.

Touch with your fingers the cover and bottom tin at the same time. This neutralizes the free negative charge on the top of the cover. The cover is now positively charged and when removed by its insulating handle will give sparks when brought near any body that can be electrified by induction. Objects connected to the ground such as gas or electric fixtures give the

best results and broad surfaces, like the wall, the worst results.

To get another spark, merely replace the cover, touch cover and bottom tin with fingers at the same time and lift up cover.

Something for Nothing?—It seems as if we were getting sparks for nothing, but really we are not. There is the work of the first rubbing, and the subsequent touchings and liftings. All this work added together is as much, and more than the energy obtained in the sparks. So as usual, we pay for what we get.

You have by this time begun to wish that the small bunches of electrical charge obtained at each discharge of the electrophorus could be bottled up and then finally let out with one big noise. This can not be done on the electrophorus itself, but the separate charges can be accumulated until they add up to make a big charge.

The Leyden Jar.—In 1745 it was discovered that a thin glass flask partly filled with water became a collector of charges when held in a person's hand. The source of the charges being connected with a wire to the water, the numerous small charges were collected in the flask. When the experimenter thought that enough had been collected, he touched the wire leading to the water and experienced a heavy shock. The next year this experiment was repeated at the University of Leyden, in Holland. The name Leyden Jar, given to it then, has stuck firmly.

CONSTRUCTION OF A LEYDEN JAR.—Find a very thin-walled glass bottle or what is better yet, buy an Erlenmeyer or Florence flask such as chemists use. The Erlenmeyer is cone shaped and so less likely to be upset. Fit a rubber stopper or a paraffined cork stopper to it. Drill the cork for a big wire nail.

Some kind of a metal ball must be obtained. Its size and material do not count. It can be a ball from the end of a curtain rod or old brass bed. It can be

a wooden or even rubber ball provided you paint it with shellac and then coat with tin foil. Some fellows form a tin foil ball about one inch in diameter by crumpling up sheets of tin foil.

The ball must be attached to the top of the wire nail which projects from the cork. If the ball is metal, solder it on, but if it is only metal-coated, stick it on with glue, or Majors Cement. Be sure that the coating of any wooden or rubber ball is connected to the wire by running several tin foil strips from the nail to the coating of the ball. To the lower end of the nail solder a wire long enough to reach to the bottom of the flask. Fig. 19A shows the completed jar.

Melt some paraffin in a deep tin dish and thrust the flask into the melted paraffin, holding flask by the bottom. Coat at least the neck, or better yet what will be the top third of the flask.

When cool, coat the outside with shellac up to the paraffin and when it is sticky, cover the entire surface with tin foil. When dry treat the bottom also in the same way.

Pour water in which a pinch of salt has been dissolved into the flask until it is half full. Insert the cork and the Leyden Jar is finished.

The Operation of a Leyden Jar.—*Experiment* 14.—The jar should be held in one hand with your fingers in contact with the tin foil coating, or it should stand on a sheet of metal which is connected by a wire to some pipe, steam, water or gas, it matters not.

Charge the electrophorus and bring the cover to the knob of the Leyden jar many times. After a dozen or fifteen charges have been put in and on the jar, for the charge is both inside and outside, you are ready to use the large charge that you have accumulated.

Use the discharger shown in Fig. 19B to touch the

knob and outer coating at the same time. You will obtain a snappy spark. The discharger as it is shown consists of a curved wire twisted into a handle in the

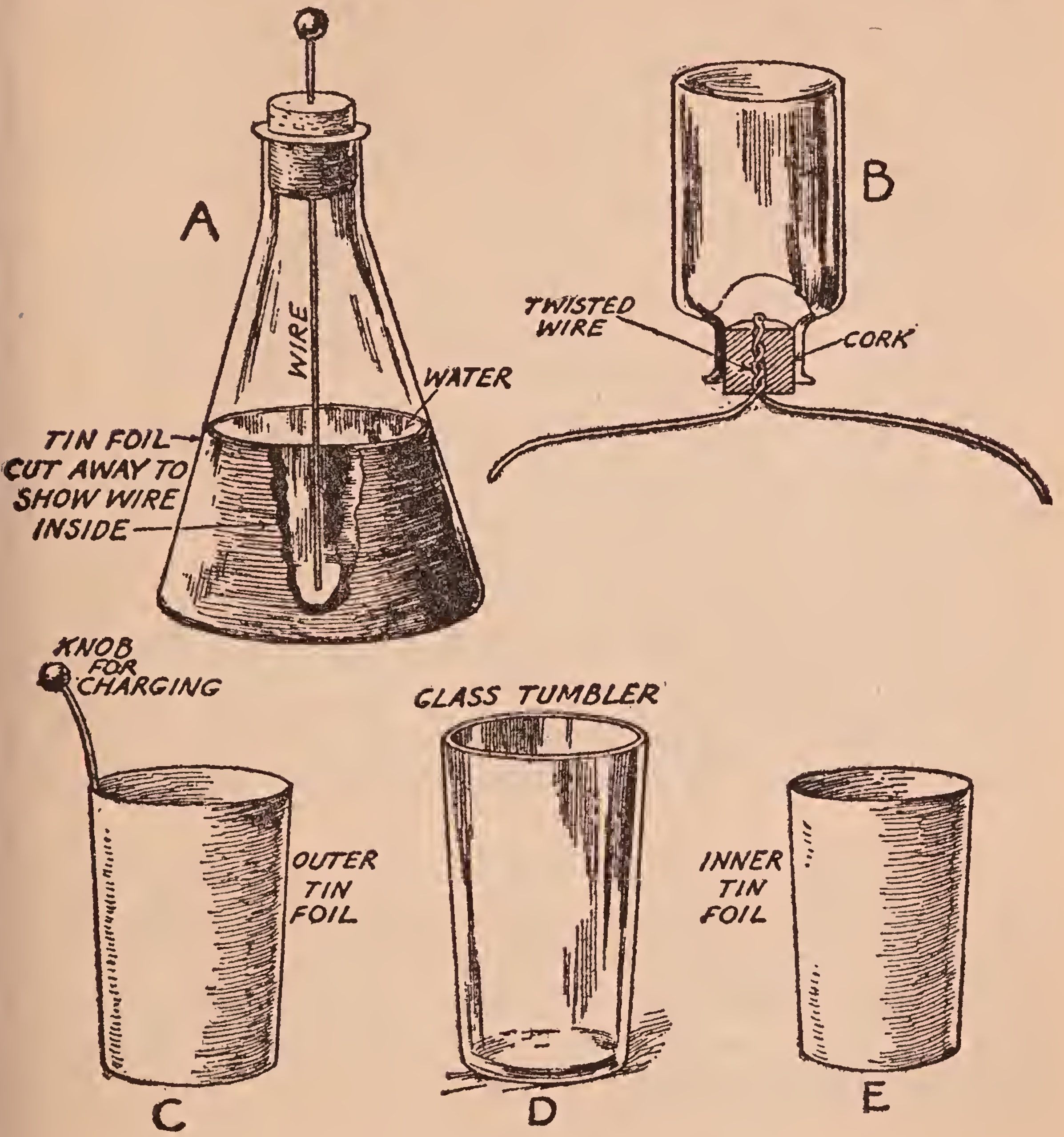

Fig. 19. The Leyden Jar.

middle. This handle is fixed in a cork and the cork set in a small bottle.

Where Does the Charge Reside.—It may have been curiosity that killed the cat of the proverb, but it is certainly curiosity that keeps science alive.

Here is a pleasant situation: we charge a Leyden jar

and discharge it. There are conducting surfaces or coatings for the inside and outside, hence, logically, the charge is on these coatings. Why ask any foolish questions, why worry? The scientific type of mind, however, does worry, does wonder if the perfectly plain reason is the true reason. Your scientist is always ready to start an investigation to see if things are really as they seem to be.

Now about this jar business, and the perfectly plain fact that the charge must be on the coatings. Franklin was much interested in these Leyden jars and performed many experiments with them.

He found of course that no coatings, no Leyden jar. Then he made a type of jar shown in Fig. 19 at C, D and E. He took a tall glass tumbler as shown at D. Placing a sheet of thin paper in the tumbler, to prevent the foil from sticking, he fitted a tin foil lining. This lining when finished could be pulled out of the tumbler. Removing the paper from the tumbler he placed the tin foil coating back in the tumbler and pressed it into a good fit. When removed again it appeared as in C.

In the same way he prepared a removable outer coating of tin foil. When this was removed from the tumbler it appeared like Fig. 19E.

You may make one yourself. A little care is required. If the coatings do not fit very snugly the experiment will still work.

Experiment 15.—Fit the coatings of this dissectable Leyden jar together and charge from the electrophorus. When well charged use the proof plane and the electroscope to show the charges that seem to be upon the coatings. Now pick out the inner coating and place on the bench, and pick out the glass tumbler and stand that on the bench. In front of you you now have the three parts of the Leyden jar.

Test the coatings for charge. You will find none on them. Place the glass tumbler in the outer coating, the inner coating in the tumbler and test the two coatings for charges, and you find charges. You may obtain a spark by using the discharge.

Now repeat the whole experiment but also try to get some charge from the glass tumbler as it stands on the bench with its coatings removed. You will find that it is charged.

This proves that the charge resides on the glass and that the coatings are merely conductors to lead the charge up to the glass surfaces.

An Explanation with Apologies.—Yes, I am fully aware that I have said two different things in the same chapter. I did say that static charges lived only on the outside of things, and I confess that I have just said that the charges were on the inside and outside of the glass. You remember that the tinny-silk or the silky-tin cone always had its charge on the outside. There seems to be a contradiction here, which must be investigated.

To be exactly sure of what we are good naturedly bickering about, let me repeat my ideas as gained from actual tests. I have found that balls, metal coffee pots with the lids on, all tin cans with or without the tops on, silk stockings turned inside out, all have the charge sitting on the outside surface. The inside surface when you can get at it to test shows no charge.

I have found that flat plates have charges on both sides, but as they are bent up into bowls the charge begins to retreat to the outside. When there is a metallic path the charge uses it to get to the outside.

So the explanation of the apparent contradiction is that when charges are led to the inside of a non-conducting material by some metal, like sheets of tin foil, the charge tries to get to the outside but cannot

find a conducting path. I could not describe the two experiments at once and so apologize for keeping the complete statements waiting while I wrote a few pages about things that needed telling, right then and there.

Static charges placed on the inside of conductors move to the outer surface. When placed on non-conductors they must stay where put. When, from the shape of the body, such as a metal bowl, the interior is not very far inside of the outside, then the charge is mostly on the outside and some on the interior.

Condensers.—A device for holding many electrons in one place, with less tendency for them to fly off, is called a *condenser*. This sounds as if a condenser were an electrical cage. In one sense it is.

Suppose we have a wire connected at one end to the negative terminal of a battery. The other end of the wire is not connected to anything, it just lies there on the table. You say that there is no stream of moving electrons. No, there is no steady stream, but for a moment there was a flow of electrons into the wire. We call this the charging current.

When the first rush of electrons reached the end of the wire, it being practically a point, some of them go sliding off into space. The higher the pressure behind them the more electrons slide off the end of the wire. If the voltage is very high, such as they use on long distance transmission lines, there is a large loss of electrons from the end of the wire.

If a flat plate of metal is soldered on the end of the wire so as to be at right angles to the wire, we have an electrical dam.

The electrons come hustling down the wire, hopping from atom to atom, and come slam bang up against the plate. The pushing and shoving behind creates a pressure which pushes the electrons out over the plate. As they hop and skip up to the edge of the plate they

Fig. 20. When Electrons Come to the End of a Wire.

cannot slide off of an edge with the delightful ease with which they slid off the point.

Just how many times worse an edge is than a blunt point like a wire, I am not prepared to say. Much depends on the roughness or smoothness of the edge, and on the thickness of the edge. The electrons will have at least ten times as hard a job sliding off the edge of the plate as they did from the end of the wire.

An inspection of Fig. 20 should make this clearer. In part A of this illustration young Edward Electron has just slid down the hand rail of the staircase. Since the hand rail ended in a point young Edward has landed in space, just like other electrons from ends of wires.

Bill Electron, when he started to slide down stairs, selected a staircase with a newel post at the bottom. You will see in part B of Fig. 20 how this prevented him from sliding off. In the same way the metal plate stopped electrons.

When two wires end in plates which are near each other and the material between them is a non-conductor, the charges on these plates act on each other. To find out about these actions you must build an experimental condenser.

An Experimental Condenser.—Select two blocks of wood about 6 inches long and 3 inches wide. Shellac them on all sides. Buy two tin pie plates or layer cake tins. Cut two slips of tin each 1 inch wide and 3 inches long. The next step is to solder to each pie plate one of these tin strips.

Now I am about to call forth that ingenuity that every boy has, that ability to adapt the means to the end. Bend the strips of tin, so that when they are screwed or nailed to the blocks the pie plates will stand upright. In order to make this possible and to make a secure mounting that will not wobble you may need to cut a groove in the block. If you find this necessary

use the coping saw to form the groove. Work slowly so that the turned-over edge of the cake tin will fit in tightly.

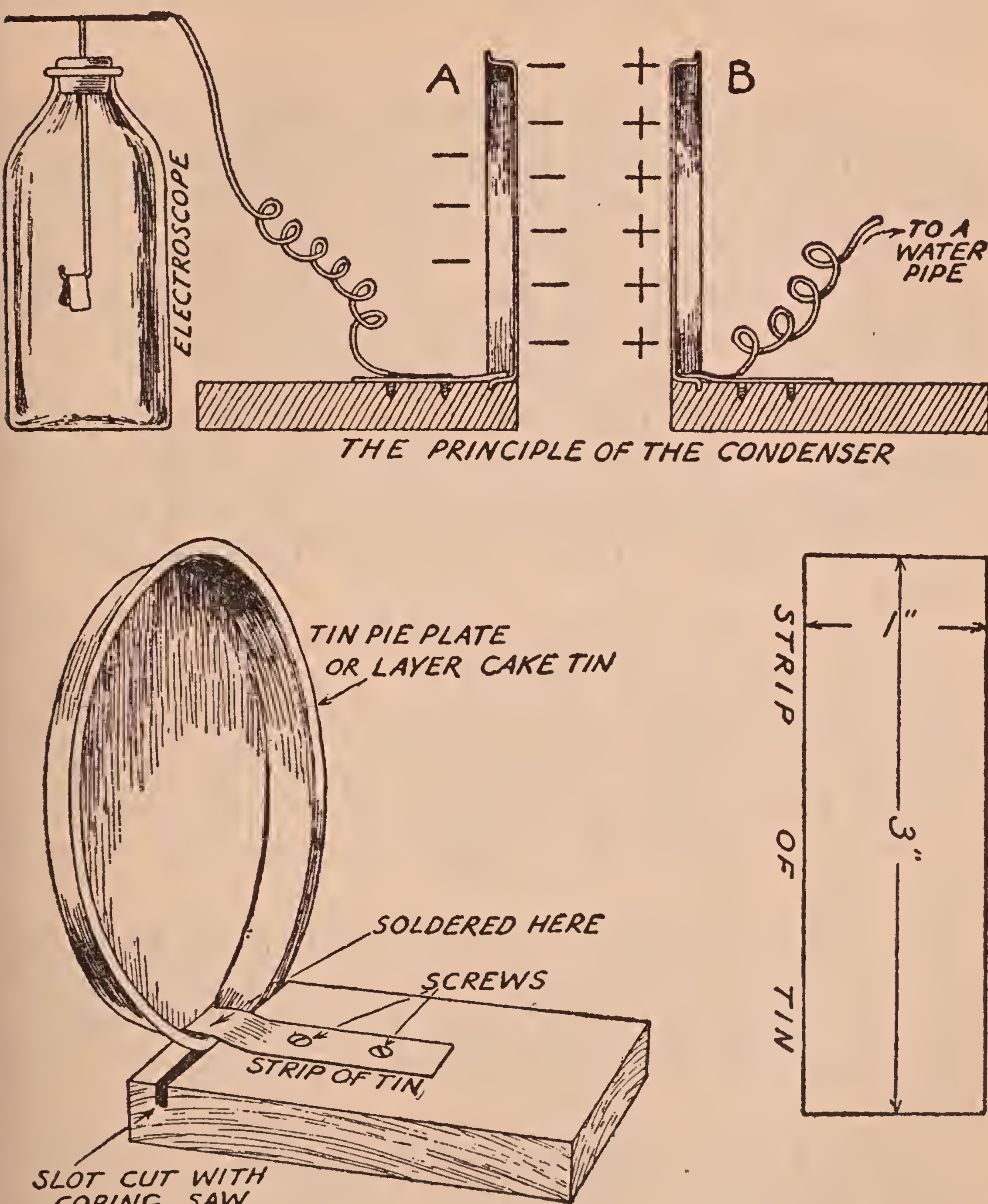

FIG. 21. THE PRINCIPLE OF THE CONDENSER.

The condenser will look like the one in Fig. 21, although the actual details of the fastenings may be different. Connect one of them to the ball of an electroscope and the other to a water, steam or gas

pipe. Lacking these, connect to the electric light *fixture.* This last sentence means to the metal work that supports the electric lamps. Do not connect to the electric light *wires.*

CAPACITY OF A CONDENSER.—*Experiment* 16.—Rub a glass rod on silk and bring the positively charged glass rod near the condenser plate A. While holding the glass rod near A, touch A with your fingers. Remove your fingers and then the glass rod. In this way the plate A is negatively charged. That is, it has upon it an extra supply of electrons.

The leaves of the electroscope should be widely separated. If they are not, repeat the whole process of charging, touching both the plate A and the knob of the electroscope so that it may be freed of positive charge.

Now push plate B up towards A and it will be positively charged by induction. The electrons on A will drive electrons from B down the wire and down the pipe to the earth. The deficiency of electrons on B causes it to be positively charged. You will notice that the leaves of the electroscope are not so widely separated.

The positive charge on B attracts electrons from the electroscope over to the plate A, thus the electroscope has less charge and the leaves drop nearer together. Push the plate B nearer and the gold leaves drop again.

Here we have a quantity of electrons on A, all repelling each other and so the tendency to leak, or sneak, away from A is strong. What restrains the electrons on A? What makes A a sort of a cage for electrons? It is the combination of the plates A and B with an insulator between them that makes the electron cage, and the closer A and B are together, the closer are the bars of this cage.

You may add negative charges to A with a proof plane until a lot of extra electrons have been added before the electroscope will register the same pressure as it would connected to A with B removed.

When B was brought near A and charged by A the charge on B was positive. The attraction between the positive on B and the negative on A drew the electrons to that face of A nearer to B. This left no *free* charge. The charge on the side of A nearer to B was *bound* by the charge on B. A *bound* charge is held so that its electrons cannot repel the electrons trying to occupy a surface near this bound charge. So we may add electrons to A without being opposed until B can no longer bind the added electrons. Then the excess electrons are free and oppose us when we try to add more. They are also free to push out along the wire to the electroscope, where they charge its leaves and make them diverge.

Evidently the presence of a grounded conductor near another conductor, yet separated from it by a non-conductor, increases the capacity of this other conductor for holding electrons. If this non-conductor is paraffin wax and the plates or conductors are very close together, the capacity of the combination may be one thousand times that of one of the plates alone.

I have said that a body never is full of electricity. We can practically always force a little more electricity on a surface. As charge is accumulated, the leakage increases. Perhaps a body is full of electricity or fully charged when as much leaks off as we put on. This would be such an inconvenient state of affairs and requires such an amount of electrons to place on the body that we have adopted a somewhat artificial definition of capacity.

The Microfarad—When a condenser develops a tension or strain of one volt between its plates after

6,300,000,000,000,000,000 electrons have been placed on one of the plates we say its capacity is one *farad*.

This condenser is such an enormous one, that for the practical work of our daily electrical jobs, we use the term *microfarad*. This is one millionth of a farad. A

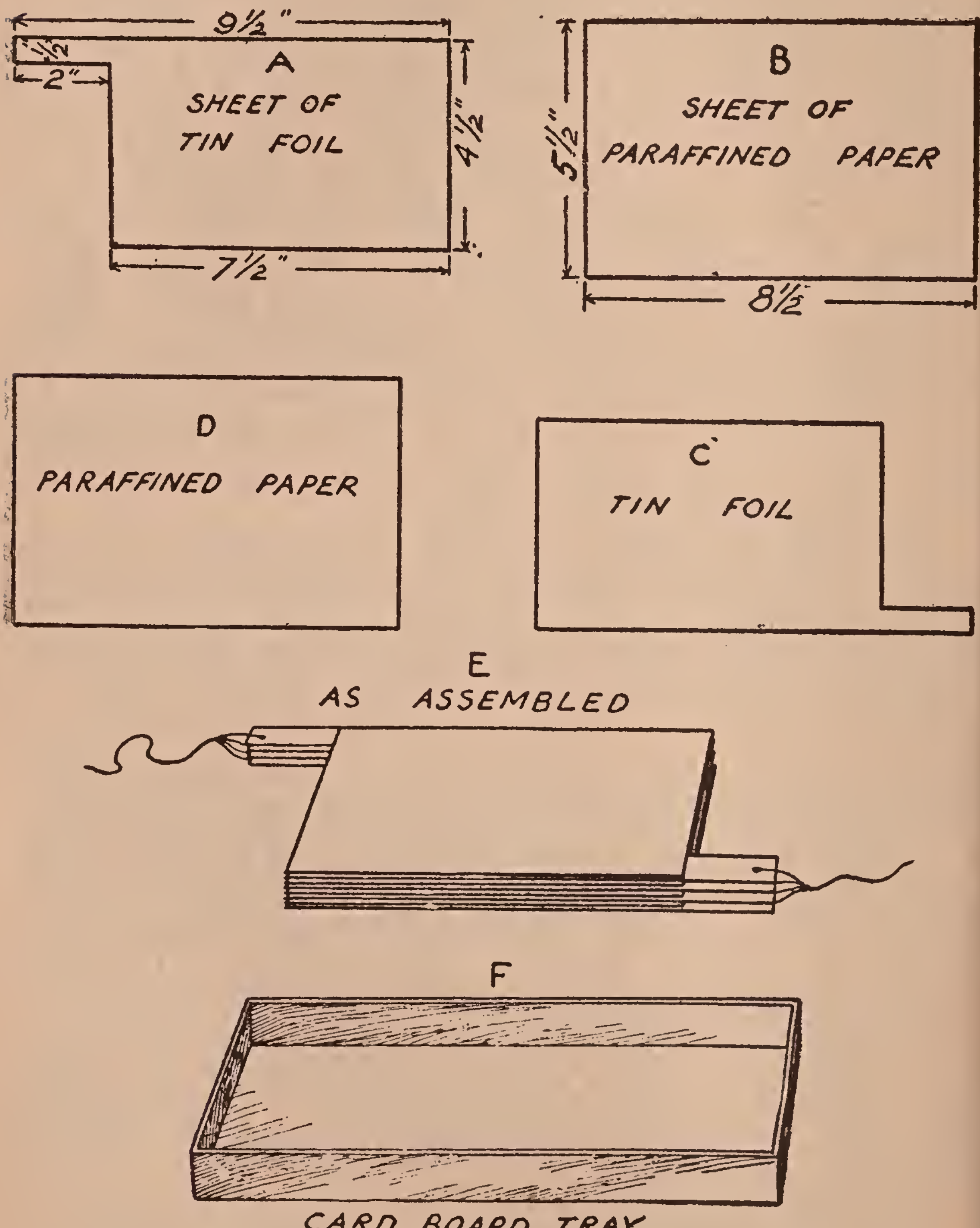

FIG. 22. CONSTRUCTION OF A CONDENSER.

condenser developing 1 volt between its plates when 6,300,000,000,000 electrons have been placed on one of its plates has a capacity of 1 microfarad.

We may build a 1 *mike* condenser so well and of such good materials, that we can stow away in it three times its capacity before it begins to leak electricity all over the experiment. A *mike* is a slang name for a microfarad.

BUILDING A CONDENSER.—*Experiment* 17.—Melt some paraffin in a broad shallow pan. Select 7 sheets of a good quality of bond paper, such as is used for typewriting. These will be 8½ by 11 inches in size. A thin sheet is better than a thick one. Cut them in half so that you have about 14 sheets 8½ by 5½ inches in size. Dip them in the paraffin.

Cut tin foil into pieces as shown in A of Fig. 22. You will need 10 of these.

Lay two sheets of the paraffined paper down as at D and on it place a tin foil sheet in the position C. On this another sheet of paraffined paper and then a tin foil sheet as in A.

Continue to lay on alternately, sheets of paper and tin foil. On top put two sheets of paper. A warm soldering copper held very close to the edges of the paper will cause the paraffined edges to adhere, when all is cool again.

Squeeze the projecting pieces of tin foil together but do not attempt to solder on a wire unless you are a dandy soldering man. Better fold the bunch of projecting ends over a wire than accidentally melt them off.

Fold up a cardboard tray large enough to leave a little margin all around the condenser. Place the assembled condenser as shown in E into the box and pour full of melted paraffin. The condenser is now electrically insulated, is moisture proof and safe from mechanical injury, unless treated very roughly.

Rule for the Capacity of a Condenser.—The greater the area of the metal plates of a condenser the greater will be its capacity. The kind of metal, or its thickness do not affect the capacity, for all the metal does is to lead the electrons to the positive charge. The square inches of surface of the plates gives the room for the electrons to "park." (The larger the field the more cars can be parked in it.)

The thinner the non-conductor which separates the plates the nearer the plates are together and the greater the capacity will be. The nearer the plates are to each other the stronger will be the attraction to draw and bind the opposite kind of charge, thus making room for more electrons on the plates and thus increasing the capacity.

When an air-insulated condenser of one microfarad capacity is placed in melted paraffin and allowed to cool in it, when it is taken out and its capacity determined, we find it has increased to two microfarads. A condenser in which glass is used gives a capacity six times as large as an air-insulated condenser and mica is a little better than glass.

Dielectrics.—The insulating material of a condenser is often spoken of as a *dielectric.* The value of a material, merely as an insulator, determines whether a spark can jump from one plate to the other with ease, or great difficulty. Aside from this property of insulating the plates from each other, every different dielectric offers a certain conductivity or resistance to the passage of the force between the positive and negative charges. Each dielectric has its own *dielectric constant,* or specific inductive capacity as it is sometimes called, which determines how good a condenser may be made from it; good used in this sense, meaning higher capacity.

CONDENSERS CONNECTED IN CIRCUITS.—When several condensers or Leyden jars, (for they are con-

densers), are connected in a circuit they are usually arranged to add their capacities.

In Parallel.—If you connect all the outside coatings together by one wire and all the knobs leading to the inside coatings together by another wire, the jars are connected *in parallel.* When thus connected the capacity of the combination is obtained by adding up the microfarads of each jar.

As a formula this is,

$$C = C_1 + C_2 + C_3$$

where C means the capacity of the group of jars or condensers and C_1, C_2, C_3 mean the capacity of each separate condenser.

For spark coils, telephone, and radio work, clumsy jars are impossible. The air-paraffin and mica-insulated condensers are sold with two terminals attached. A glance at Fig. 11 in Chap. II will show you how to connect such condensers in parallel. Just pretend that the cells are condensers.

In Series.—When the outer coating of one Leyden jar is connected to the knob of another the arrangement is called *in series.* The capacity of two jars connected in series will be found by dividing the product of their microfarads by the sum of their microfarads.

In a formula this is,

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

where the letters mean the same as they did in the previous formula.

What I would call regular condensers, that is radio condensers and such, may be connected in series very much like the cells in Fig. 4 Chap. I.

A Bit of History.—Thales, who lived 600 years before Christ was born, knew that amber and jet when rubbed with woolen cloth, would attract feathers, leaves and bits of straw. Pliny, writing in the year 70, tells about such experiments.

William Gilbert in 1600 used the word *electrica* to denote substances which acted like amber when rubbed. He coined the word from the Greek word "electron" which means amber.

William Barlowe, in 1618 went a step further, and called the experiments, *electrical* ones.

Otto von Guericke, in 1663, mounted a ball of sulphur on an axle and generated charges by holding his warm hands against it as it was rapidly revolved. Sir Isaac Newton and Hawksbee, each about the same time, in the year 1709, used a glass globe obtaining the same results.

The attraction between unlike, and repulsion between like charges was discovered by du Fay in 1733. He also showed that everything may be electrified by friction.

The Leyden jar was made by von Kleist, and then Watson, about 1775, succeeded in leading the discharge of a Leyden jar along wires.

Benjamin Franklin from 1750 to 1760 made important experiments and devised good explanations for the things of which, from his observation, electricity was the cause.

Faraday in 1833 showed that all electrical charges, whatever their source, were fundamentally alike.

Many scientists had separately come to the conclusion that the study of electricity in gases and in vacuum would reveal a lot about the true nature of it. Crookes in 1872 was working along these lines. J. J. Thomson was hard at work in 1899 on the same subject.

From this point the study of electrical charges was taken up by a great number of the scientists, in com-

bination with the work on the constitution of the materials in our world.

To Thomson, Rutherford, Wilson, Soddy and Millikan we chiefly owe the exact knowledge of what electrical charges are.

CHAPTER VI

PORTABLE SOURCES OF CURRENT

ELECTROMOTIVE FORCE
- Voltage
- Potential Difference

E. M. F. OF CELLS

VOLTAGE OF CELLS

RESISTANCE OF CELLS

QUANTITY OF ELECTRONS OBTAINED

BATTERIES

TYPES OF CELLS
- High Voltage Cells
- Low Voltage Cells
- Large Current Cells
- Low Current Cells
- Wet Cells
- Dry Cells
- Open Circuit Cells
- Closed Circuit Cells
- Primary Cells
- Secondary Cells
- Storage Cells

THE LEAD AND ACID STORAGE CELL
- Experiment 24

THE PRACTICAL LEAD CELL

THE ALKALINE CELL
- Edison Storage Cell

USING STORAGE CELLS

SIZES OF STORAGE BATTERIES

THE AMPERE-HOUR

CHAPTER VI

PORTABLE SOURCES OF CURRENT

Tame Electricity in Small Packages.—I have always thought of static charges as "wild" electricity, for it occurs everywhere, whether wanted or not. Reminds me so much of weeds. Just for the sport of it, today I have been trying to dodge static charges. Did I? I did not. When I walked across the floor to turn on the electric light I got a shock from the switch. When I tried to comb my cowlick it became an electrified shaving brush on the top of my head. When I wrote, the sheets of paper stuck together. I heard static on the radio, and finally after finishing a chapter of this book, I decided to change to skating togs, for a little exercise before dinner. Peeling my coat off in jig time, I developed a charge. You can't dodge these wild charges.

For many purposes we want small quantities of thoroughly tamed or domesticated electricity. A calm kind that will eat out of our hand, so to speak. That when unleashed will not go very far, nor forcibly.

The nearest we have to this form of electricity is the current from cells, for from the cells of various kinds we get streams of electrons at low pressure.

The best materials are zinc and copper or zinc and carbon. Since the zinc is used up in the work of a cell, it seems as if the electricity came out of the zinc.

The best cell for the job depends upon the character of the work and will be fully discussed later on.

Portable Sources of Electricity.—I seem to have started something, for when my son reads this I am

sure there will be an argument as to what I mean by portable. You see, yesterday he brought home a 110 ampere hour storage battery. When he arrived he was "all in," but some of the battery acid was out. When he rested up a bit, he told me that surely I must have meant that it was a 110 pound battery. However, if you are quite muscular, even a lead storage battery is portable. It was Edison himself who said that a lead storage battery was "*very* wet and *very* heavy."

We shall include in the class of portable sources, primary cells, secondary cells, magnetos and the motor generators used in automobiles. This chapter will deal with primary and secondary cells, or as they are more frequently called, *cells* and *storage batteries*.

Why Cells Furnish Current.—There are two places in every cell where the wires which lead to the work to be done should be attached. These places are charged. This being true, a Leyden jar or a condenser should furnish current, for they have two charged places. When it appears that something ought to work, you should experiment to see whether it will or not.

CURRENT FROM A LEYDEN JAR.—*Experiment* 18.—A piece of glass tubing of small bore is cut a little longer than a steel knitting needle. On it is wound a spiral coil of magnet wire. Keep the turns one quarter inch apart. Slide an unmagnetized knitting needle in the glass tube. Stand a Leyden jar on the wire from one end of the coil and arrange things so that the wire from the other end of the coil is not close to the jar. Three inches away will do. As shown in Fig. 23, with the discharger connect the knob of the jar to the free wire. The electrons will then rush through the wire and magnetize the needle.

Before this experiment the knitting needle should have attracted both ends of the moving magnet in the

galvanoscope. After the experiment, the knitting needle should attract one end of the galvanoscope magnet and repel the other. This shows that the knitting needle is magnetized, and that in turn shows that current flowed from the Leyden jar.

Cell Terminals Are Charged.—The places where the wires are attached to a cell are called *terminals.*

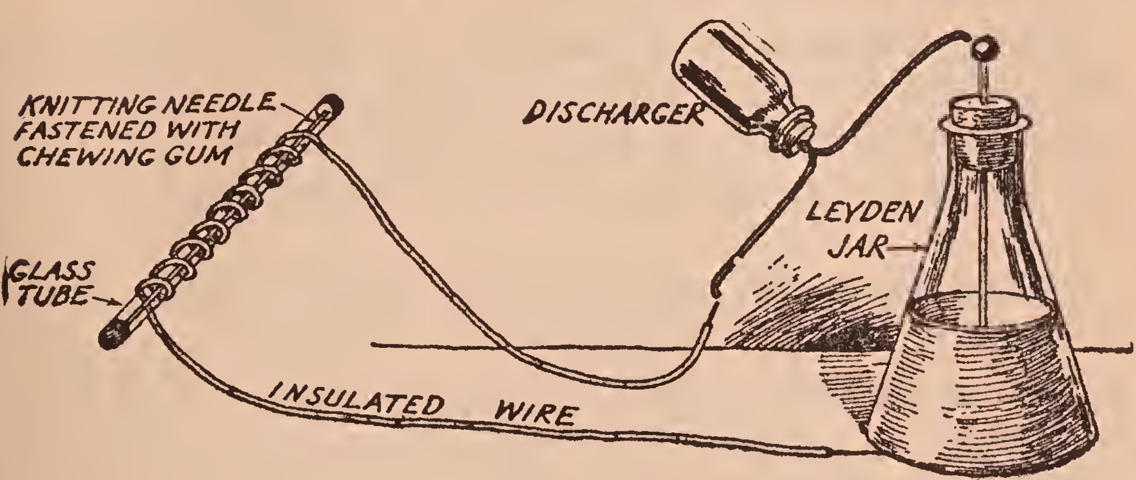

FIG. 23. MOMENTARY CURRENT FROM A LEYDEN JAR.

One is the positive terminal, the other the negative terminal. These terminals are charged just as the coating of a Leyden jar or the plates of a condenser are charged.

Experiment 19.—Cut a circular plate of sheet metal the same size as the plate on your electroscope. Solder a wood screw to it and make a small glass bottle handle for it just as was done for the upper part of the electrophorus, see Fig. 17. Cover its *lower side* with shellac.

Arrange five dry cells in series as in Fig. 4 or use one 22-volt radio B battery. Attach a wire to the free positive terminal and one to the free negative terminal. If you have followed Fig. 4 exactly, simply make the positive and negative wires each about two feet long.

On the metal plate of the electroscope place the shellaced plate. Touch top and bottom plates with your fingers to be sure that they are neutral.

Lift the upper plate by its insulating handle. Nothing should happen and nothing does happen. Now we are ready. Take the positive and negative wires of the battery, holding them by their insulating coverings. Touch one to the bottom of the bottom plate, the other to the top of the top plate. Remove the wires. The two plates are charged oppositely and these charges bind each other so that the gold leaves are neutral.

Using the insulating handle, lift the top plate up. The gold leaves now diverge because the charge in the lower plate is no longer bound. This charge, now free, spreads over the electroscope and charges the leaves.

What Charged the Electroscope?—Why, only the battery could have charged it. This shows that the terminals of cells carry electrical charges. Well then, why not touch one of the wires from a battery to the plate of the electroscope? Because you would get no results. The few electrons sliding off the end of a negative wire can not charge the electroscope, but if we provide a nice waiting room, like a condenser plate, then the electrons accumulate in this plate and enough collect to charge the electroscope.

The Source of the Current.—The charge on the negative terminal sends electrons out into the wire attached to it. As fast as they move away, the charge of the terminal disappears. If you used a Leyden jar as in Experiment 15, there would be one rush of electrons and the flow would cease until the jar was recharged. A dry cell acts in exactly the same way. Each bunch of electrons leaving the negative terminal discharge this terminal, and if it were not for the chemical action within the cell continually recharging the terminal, the flow of electrons would cease. This tells us how to define a cell.

Definition of a Cell.—A cell is a device in which chemicals are used to continually maintain (keep up)

the potential (charge) of one terminal while keeping the other terminal either neutral or charged oppositely.

A Bit of History.—In 1786 Galvani observed that when copper and zinc were held in contact like an inverted V and touched to the leg of a frog, that electricity was produced. He thus produced electricity by chemicals. It was not until 1800 that Volta made a true chemical cell.

Volta's cell consisted of two strips, one of copper and the other of zinc, standing in diluted sulphuric acid. Their dry ends touched, but their wet ends were separated. When the dry ends were held apart and were electrically connected by a wire, a current flowed in the wire. This simple cell is called by some the *galvanic cell* and by others the *voltaic cell.*

Why a Cell Gives Out Energy.—Energy from the heat of the sun and from its ultra violet rays has been locked up in the minerals of the earth. When this energy is released in the chemical actions of a cell it spends itself in pushing electrons.

Notice that I say when released in the chemical actions of a *cell.* There is electricity in everything, but the hard job is to get it out and to get it out in such a way that we can catch it.

Suppose you throw a few shovelfuls of fine damp coal into the fire box of your furnace and forget to close the door. The result that you get is not the fault of the coal. It was full of heat units and you gave them a chance to get out, but not in the proper manner. Hence they failed to heat the house. What a difference there would have been if everything had been just right.

So it is with electricity. We must treat the materials correctly else the power produced may not be worth the money we have spent.

One pound of zinc dissolved in sulphuric acid will give out 1026 British thermal units of heat but no electricity. In a cell we might get 26 units of heat and the

1000 units not as heat but as electrical energy. If everything worked perfectly, one pound of zinc should give 1/100 of a horse power for 100 hours.

How Cells Push Electrons.—Suppose we make, operate, and then talk over, the action of a very simple cell. To prepare this cell we proceed as follows:

MAKING A SIMPLE CELL.—*Experiment* 20.—Place a glass nearly full of cold water in a basin, for what we are about to do may crack the glass and spill a corrosive liquid. In a test tube pour a teaspoonful of water. Slip a rubber band around the tube to mark the height of the liquid. Empty the tube and dry the inside fairly well; at least shake out all the water that you possibly can. Pour some concentrated sulphuric acid or oil of vitriol, as it is also called, into the tube up to the marker. Slowly pour this teaspoonful of acid into the glass of water. Stir slowly, but well, with a glass rod. Be careful to rinse the test tube well before laying it down.

Never pour water into sulphuric acid, as it may get so hot that it will bubble violently and spatter acid on your skin or clothing. When this mixture of acid and water is cool, and not until then, may you put in the electrodes.

To a strip of copper of convenient size for your glass—it can not be too big—solder a copper wire, or a binding post, if you have one.

Prepare a rod of zinc in the same way. Sheet zinc is poor stuff for a cell, as it is eaten up so quickly.

Place the zinc and the copper in the glass of acid and connect the wires to the galvanoscope with its resistance coil in series. The hook-up is given in Fig. 9.

This cell is pulling electrons out of something and pushing them out on the wire connected to the zinc rod.

How can a cell push electrons? To answer that we must consider what is going on inside of the cell.

THE ACTIONS INSIDE OF A CELL.—When you poured the sulphuric acid into the water a chemist would have said that you were ionizing the hydrogen sulphate.

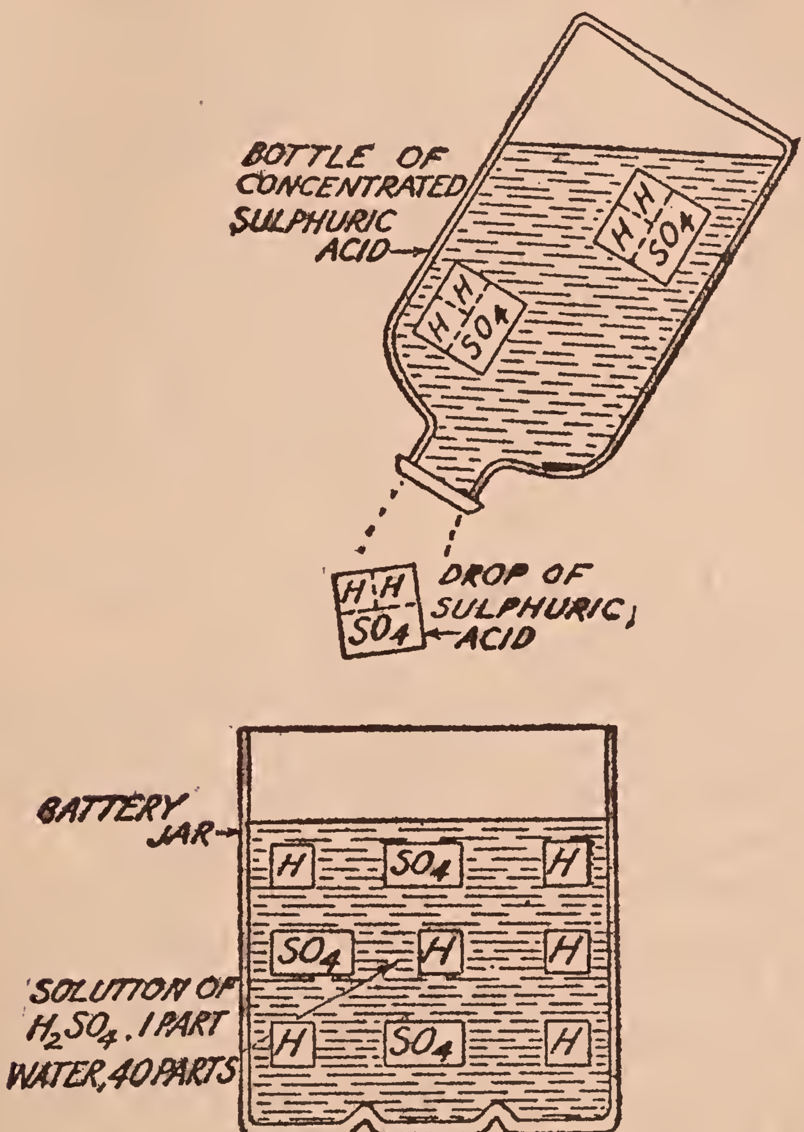

FIG. 24. WHEN SULPHURIC ACID IS POURED INTO WATER.

You will get a better idea of what this means by an examination of Fig. 24 than if I wrote three pages about it. The illustration shows what happens when molecules of sulphuric acid fall into water and become ionized, each molecule of sulphuric acid forming three ions, two of hydrogen and one of sulphate.

Sulphuric acid is a combination of two atoms of hydrogen and one radical of sulphate. The sulphate part is not a molecule nor an atom; it is a group of atoms which stick closely together. For all ordinary chemical actions a radical is inseparable.

In a molecule of sulphuric acid the two hydrogens and the sulphate are held together by two electrons which act as links. The two hydrogen atoms are feeling, each separately, of course, "That electron is in my outer shell. If it were not for that electron I would have a 'gone' feeling in the outer layer of myself. Whenever I feel that way I develop most *positive* qualities. I really feel to the extent of one whole positive charge. I agonize over the situation, but those unfeeling scientists say I am *ionized*. But, thank goodness, there is that electron and I feel quite neutral and happy."

Now, the humor of the situation is that the sulphate is also having a little talk with itself.

Most of the weight of these atoms and radicals is situated in the nucleus of each atom. Since these atoms do wonderful things, I shall assume that the brains of an atom is in its heaviest part, its nucleus.

So the nuclei (plural of nucleus) of the sulphate are having a little chat. "Thank our lucky stars! If it were not for those two hydrogen atoms taking some of the responsibility of those two electrons on their shoulders we would still be in a frightfully *negative* condition. It is such a responsibility, hanging on to two electrons, more than we really care for. Oh, yes, of course we like electrons; we are very fond of electrons, but you know those two extra ones were such a care. They made us so *negative*. Nervous? No. I said *negative,* but after all, with two extra electrons why should we not feel nervous? When we have them exclusively to ourselves, the scientists say 'That sulphate is ionized.' Perhaps they are right; certainly we

know that we feel very negative. But now we feel quite neutral, for those two silly hydrogen atoms actually each think that one of those electrons belongs to it. Of course, those two electrons are a sort of common bond between us, the sulphate, and them, the two hydrogens. You know, whenever we really get those two electrons all to ourselves, we can't stand the nervous strain and we always hunt around and pick up something that is fond of electrons and will play with them. No, no, I don't mean just these special two electrons; all electrons look alike to us. As long as someone will play with two, any two, why sulphate is willing to form a company. The other fellow or fellows think they own the two electrons, so they are happy. We know we own them; that we can't get completely rid of them, but we can feel quite neutral as long as any two of our electrons are not exclusively in our care."

All of these two musings of the hydrogen and the sulphate occurred in the bottle of sulphuric acid. As soon as you poured the hydrogen sulphate into the water there was a great commotion. There was the thirsty sulphuric acid combining with the water faster than you ever combined with a soda. This created the heat that you noticed. But that is not all. Most of the hydrogen sulphate was compelled to part company. The truly advantageous combination of hydrogen and sulphate in which some two electrons kept both parts of the compound satisfied is now broken up. We say that the sulphuric acid is *ionized.* Take another look at Fig. 24.

When the sulphate broke away it took two extra electrons with it and became negatively charged. The two hydrogen atoms each are short an electron and so each becomes positively charged.

Electrolyte, Electrodes, Poles.—When an ionized solution is used as the liquid part of a cell it is called the *electrolyte.* When unlike materials are placed in an

electrolyte these pieces of material are called *electrodes.* The dry ends of these electrodes are called the *poles* or the *terminals* of the cell.

ANOTHER DEFINITION OF A CELL.—A cell is a combination of an electrolyte with two solid materials, one of which is dissolved by the electrolyte, while the other is not.

Inside of the Cell Again.—Into your glass of sulphuric acid electrolyte place the zinc and the copper electrodes and connect the poles of this cell by a wire. It would be better yet to connect it to the galvanoscope as in Fig. 9.

A TALK ABOUT COPPER.—An atom of copper consists of a nucleus in which are closely packed 58 protons and 29 electrons. Surrounding the nucleus are 29 more electrons. When an enormous number of these atoms have been melted together and cast into a form, or electrically plated into a piece and then rolled into sheets or drawn into rods and wire, we have these atoms fairly close together. Not close, as *you* would figure closeness, but close for atoms.

Pieces of metals have some of the electrons skipping from atom to atom and sometimes an electron temporarily belongs to two atoms. This leaves some electrons free. When a piece of copper is placed in an electrolyte which does not dissolve it, the copper is ready by means of its free electrons, to deliver electrons to any ion which needs them.

Definition of an Ion.—An atom or group of atoms (radical) having an excess or a deficiency of electrons is called an *ion.*

A TALK ABOUT ZINC.—What I have said about the copper in general applies to the zinc. The nucleus of zinc contains 60 protons and 30 electrons. There are 30 electrons around the nucleus.

When zinc is placed in an electrolyte which dissolves it the zinc seems to take electrons from the ions of the

electrolyte, and these, piling up on the zinc, produce such a crowd that they are pushed off and flow away in a electron stream along the wire attached to the zinc and copper poles.

Thus the copper shoves off the electrons which it receives into the ions of the electrolyte and the zinc

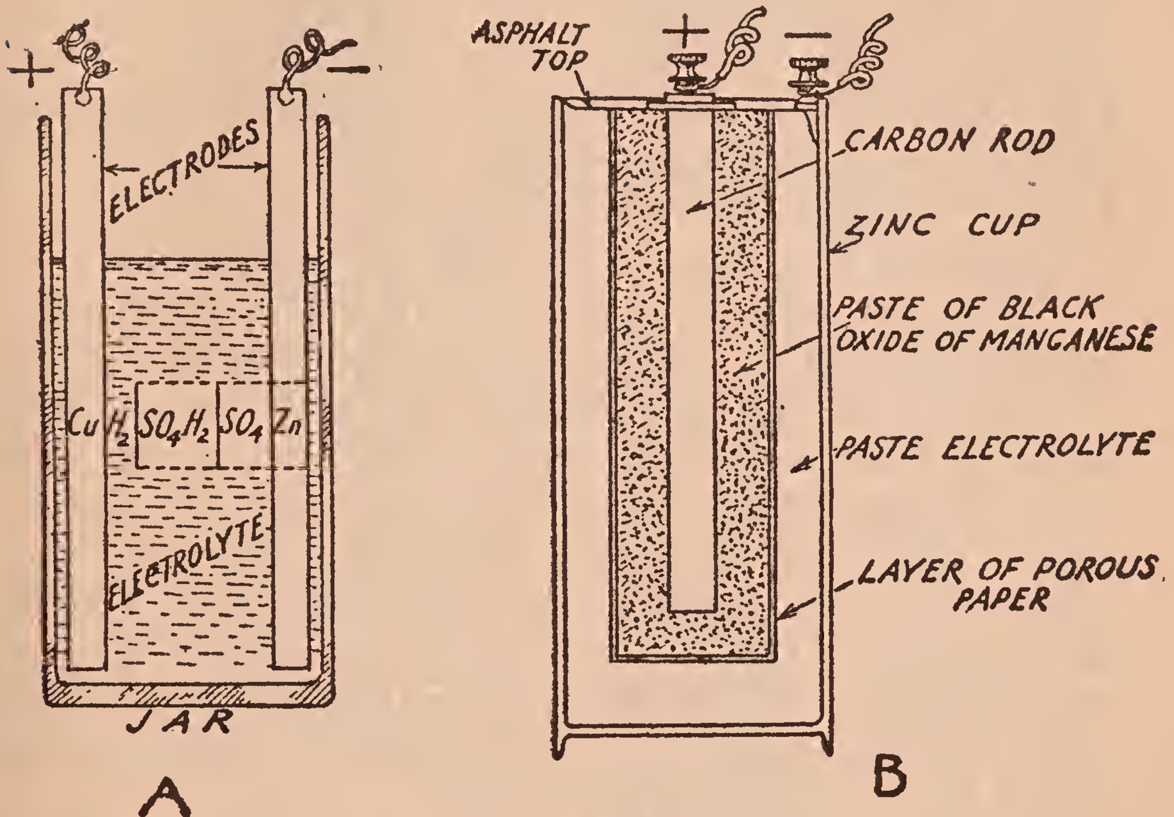

Fig. 25. Simple Cells.

receives the electrons and pushes them out into the negative wire as *electrical current.*

I know that I have not fully told why the cell furnishes current.

There were many interesting and necessary details to be explained, but now I am ready for the explanation of why the chemical actions result in a flow of current.

The Chemical Action in a Simple Cell is represented at A in Fig. 25, which shows a glass jar with a strip of copper and a rod of zinc standing in an electrolyte of dilute sulphuric acid.

Remember that the molecules of sulphuric acid which were electrically neutral when poured into water became hydrogen ions positively charged, and sulphate ions, negatively charged, because the sulphate stole two electrons as it was forced out of the sulphuric acid. The zinc electrode is composed of atoms of zinc, each of which has two electrons which are so far from the nucleus that they can get loose rather easily. From the surface of the zinc electrode, atoms are frequently darting out into the electrolyte. As they do this, they leave two electrons behind on the electrode.

There are two important results from this action.

When an atom of zinc hops off, leaving two of its electrons behind, it becomes positively charged. Hence the negatively charged sulphate ion and the positively charged zinc ion attract each other and would form actual molecules of zinc sulphate were it not for the water which keeps them separated. The electrons left on the zinc electrode are not needed by the atoms of zinc there. Each has its proper number of protons and electrons. These free electrons accumulate on the electrode until there are so many that they are crowded off on to the wire attached to it.

This second action causes a flow of electrons away from the zinc pole of the cell, causing what we call a current of electricity.

We must not forget the hydrogen ion—two of them, in fact—that came into the electrolyte along with each sulphate ion. These are positively charged. They are therefore repelled by the positively charged zinc ions which are around the zinc electrode.

Probably each hydrogen ion wanders around until it gets near the copper electrode. This is composed of copper atoms having two electrons loosely attached. The hydrogen ions, being positively charged and hence looking for electrons, take the needed electrons from the copper atom of the electrode. This leaves the cop-

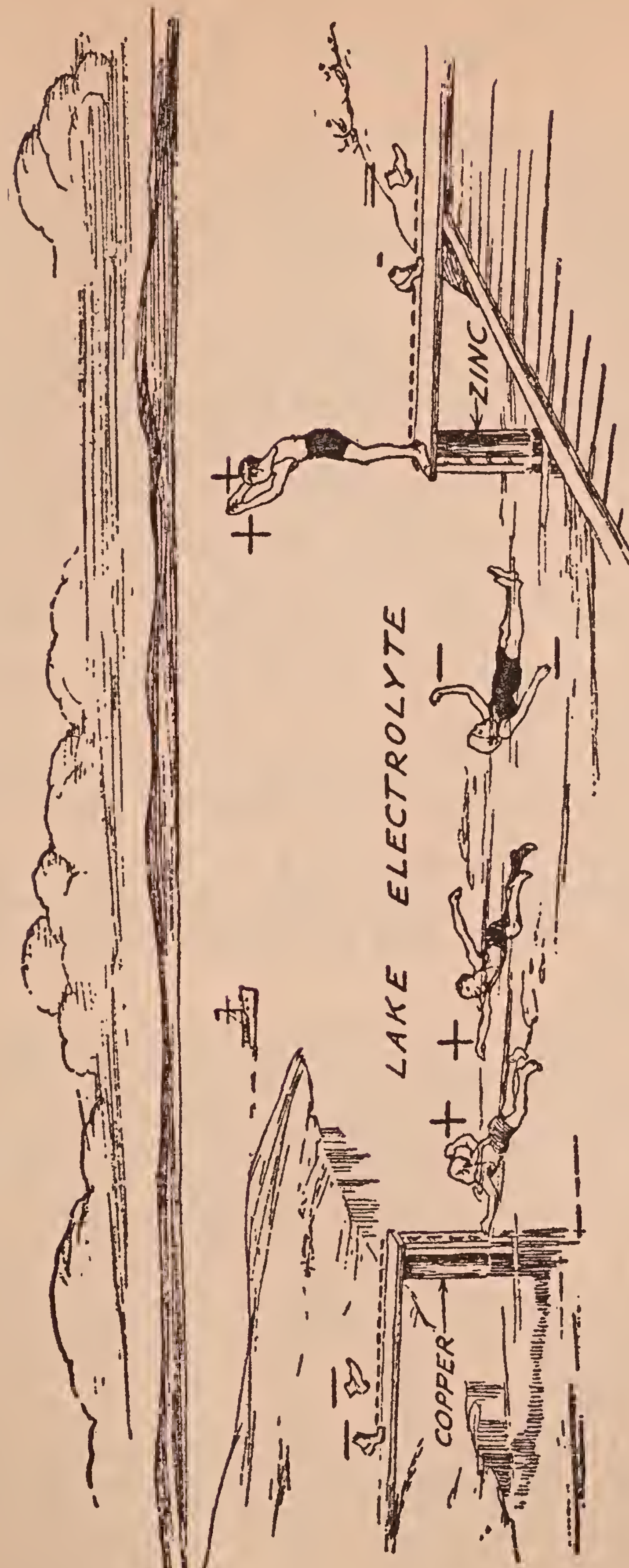

FIG. 26. A PRIMARY CELL.

per electrode short of electrons. So it is now composed of atoms and ions and is in great need of electrons.

If we now connect the wire from the zinc pole to the copper pole, then the electron forced out on this wire by the zinc electrode will flow around and be greedily pulled out of the other end of the wire by the copper electrode.

Thus you see the chemical action of the cell makes the zinc electrode a pusher of electrons. And the copper electrode becomes a puller of electrons, and so a steady stream of electrons flows through the connecting wire, and the cell furnishes an electric current.

The action of this simple primary cell might stick in your mind better if you could get a vivid picture of what is going on in the cell. I am sure Fig. 26 will help you to do this.

In Lake Electrolyte there are two piles, one of copper, the other of zinc. Sam and Bill Hydrogen, twin brothers, have been swimming around with Miss Sulphate and having a grand time. The Hydrogen twins have done the swimming and Miss Sulphate has been lazily floating.

Seeing Ed Zinc, one of the atoms of zinc, for the Zincs are a large family, she calls, "Come on in; the water (acid) is fine." Kicking off his two sneakers (electrons) Ed Zinc acquires two positive charges and diving into the water (acid) becomes an ion.

Ed Zinc's sneakers (electrons) race madly away on the plank (wire) and start to run around the margin of the lake (the circuit). They will ultimately reach the copper pile.

As soon as Ed Zinc is in the water (acid) Miss Sulphate devotes her time to him. Sam and Bill Hydrogen are as sore as wet pups. They swim to the copper pile, intending to put on sneakers, and sure enough

here are the sneakers galloping down the path (wire) to the copper pile.

Sam and Bill Hydrogen always were queer about sneakers (electrons); one for each of them seemed to give them perfect satisfaction. So the two of them will remove from the copper pile as many electrons as Ed Zinc started off from the zinc pile.

A Practical Cell.—Such a cell as we have been talking about is not practical; in fact, no cell containing a liquid is a pleasant companion either in experimental work or practical everyday use.

The cell shown in Fig. 25 B is called a *dry cell.* It consists of a zinc can, which acts as a container and also as the zinc electrode. In the center is a carbon rod. The electrolyte is damp instead of wet and sloppy. It is sealed with asphalt cement, and will work just as well standing on its head as if it were in its natural position. This cell will be fully described a little later on.

The Ideal Cell.—Such a cell would have:

1. Small resistance to the passage of electrons through it.

2. A large force to push electrons at one pole and a large force to pull electrons at the other pole.

3. The same pushing and pulling force for any electron stream. We would then have a cell which did not weaken under heavy work.

4. The ability to produce electricity from cheap chemicals.

5. No waste of chemicals. Every speck of the chemicals should produce electrons, pushing them out of the zinc pole and pulling them in at the copper pole.

What the Simple Cell Will Not Do.—Since the simple cell does not have the qualities we have listed in the last paragraph, it would be well to find out what it will do and won't do.

1. It will not keep on pushing and pulling electrons

with the same vigor. It gets exhausted and requires a rest.

2. It will not use chemicals economically.

This means that there are two serious defects in the simple cell that we must remedy. We have found no material for the negative electrode as good as zinc unless we pay a very high price. Considering quality and price together, zinc is the best for the negative electrode. Its price is high enough to make us very anxious to prevent waste.

Local Action.—This is the name applied to the chemical action by which zinc is wasted. You will understand what happens and how it happens better if you try an experiment.

Experiment 21.—Prepare a simple cell and connect its terminals by a piece of wire about six feet long. Watch the action of the zinc. Notice that it dissolves much faster at some places than at others. You may judge the speed of dissolving by the amount of bubbling. Chemically pure zinc will show no bubbles.

Zinc of the ordinary commercial grade of purity contains little particles of iron and carbon. These, with the zinc in which they are embedded, form little local cells in which there is a flow of electrons. Since these electrons never get into the wire connecting the poles of the cell they can not be made to work for us. The zinc is eaten up to no useful purpose.

Could we coat the zinc with a paint that would cover the iron and carbon pieces, protecting them from the acid, yet which would permit the zinc to pass through it to the acid, our troubles would be solved.

Amalgamation.—Fortunately there is such a coating. Forming such a coating and watching it work is the best way to test the value of *amalgamating* the zinc.

Experiment 22.—Remove the zinc rod from the simple cell. Place it in a shallow dish with a few drops of mercury. Using an old tooth brush or a rag tied on a stick, rub the mercury over the surface of the rod. It becomes shiny and silvery. Rub until every part of the surface is *amalgamated.*

You may need another drop of mercury, but hard rubbing will spread it nicely. You have formed an amalgam of zinc and mercury and you have not affected the carbon and iron pieces.

Set up the cell, using this amalgamated zinc. Now there are no bubbles on the zinc, and no zinc is wasted in local action. None? Well, not quite none. Before amalgamation perhaps half of the zinc might have been wasted, but now not more than 3 per cent will be dissolved without furnishing us with current.

An amalgam is a soft alloy of mercury and any other metal. Keep mercury away from your jewelry and money. This amalgam covers up the iron and carbon pieces with an acid-proof coating, yet the zinc passes through the soft amalgam and is dissolved by the acid.

Experiment 23.—Connect your simple cell to the galvanometer in the hook-up of Fig. 9. Do not close the circuit until you are ready to make the observations. Just as you close the circuit notice the reading of the galvanometer.

In a few minutes the reading will be less and soon the reading will drop so low that you will know the cell is not pushing in any electrons. The cell is *polarized.*

With a sliver of wood, scrape off the bubbles adhering to the copper strip. Give the electrolyte a good stirring, and a glance at the galvanometer will show that the cell is on the job again.

Polarization.—When a cell, by its chemical action, makes the positive electrode too much like its negative electrode, chemically speaking of course, then the cell does not pump electrons with the pressure that it used to. This condition is called *polarization* and is caused by a coating of bubbles of hydrogen gas forming on the positive electrode.

Polarization Cured.—Since it is the hydrogen which causes the polarization, let us get rid of the hydrogen by turning it into water. This can be done by adding sodium bichromate to the cell. This chemical, with its large store of oxygen, will oxidize the hydrogen to water.

As soon as we do this, there is a continuous dissolving of the zinc even when we are not using the cell. We remedy this by placing the copper in an inner jar of porous earthenware, like an unglazed flower pot. The bichromate solution *may* be poured in around the copper.

The zinc is not eaten up wastefully now, but to our dismay, we would find the copper dissolving. This we avoid by the use of a carbon plate, which makes as good a cell as the copper and zinc arrangement.

This bichromate cell, sometimes called the Fuller cell, avoids polarization but is not suitable for home use. The liquid in it is far too corrosive.

The cell whose internal construction is shown in Fig. 25 B is safe to use, since it is sealed. The depolarizer is a solid material, black oxide of manganese. Being a solid, it absorbs the hydrogen very slowly, but in time it turns to water.

To find out how well it depolarizes, connect the cell up according to Fig. 10. Close the circuit and, keeping it closed, watch the reading of the galvanometer. The reading will diminish. The cell keeping a high reading for a longer time has the better depolarizing action.

Polarization Prevented.—If a cell could be designed so that no hydrogen came near the copper electrode there would be no chance for polarization.

The Crowfoot or Gravity Cell.—In this cell, shown in Fig. 27 A, the chemical action keeps the hydrogen away from the copper.

To put the cell together, place the copper element at the bottom of the jar. Fill it three quarters full of

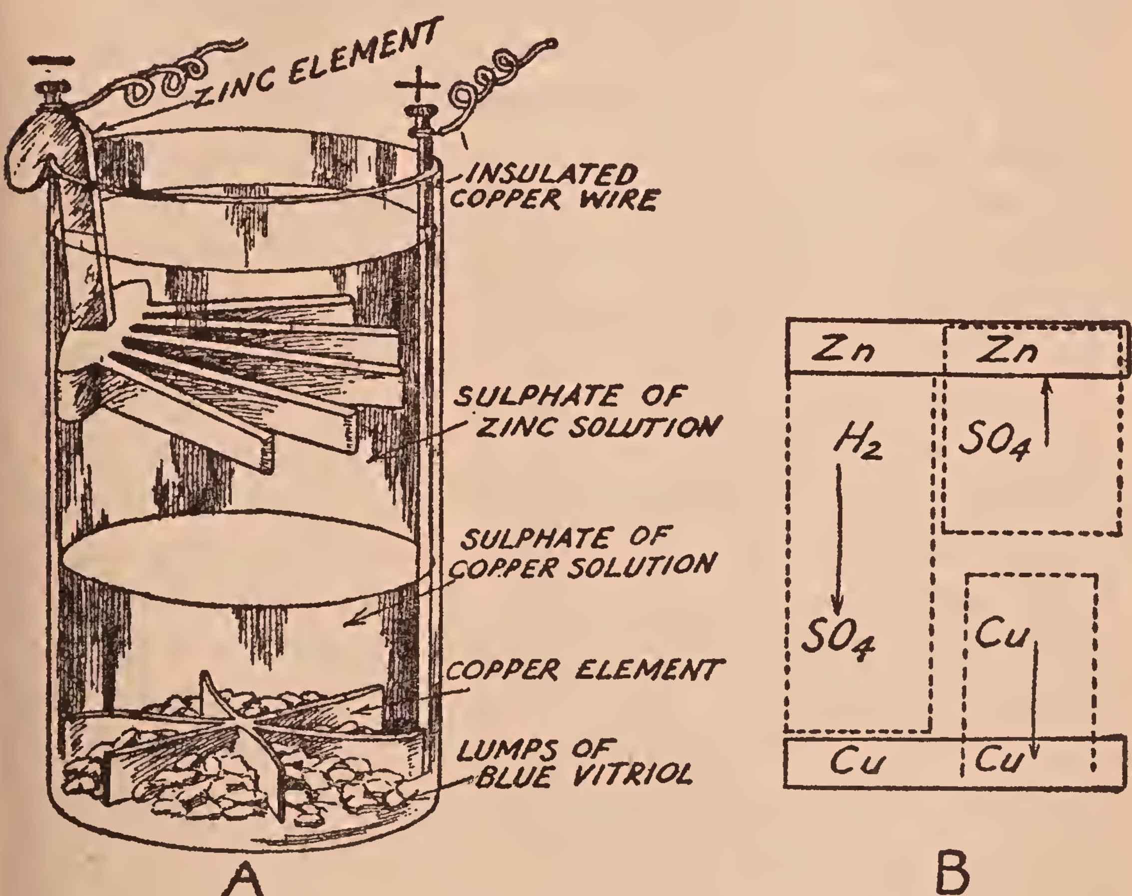

Fig. 27. The Crowfoot Cell.

diluted sulphuric acid. One teaspoon of acid to 40 of water is correct. Use the test tube measure for the acid.

Drop in some large clean lumps of copper sulphate or blue vitriol, as it is also called, so that they fall in between the leaves of the copper electrode.

Hang the zinc electrode on the edge of the jar. Connect the wire, and put the cell to work. At first you

will find the cell weak, but use will improve it. Never permit the cell to stand idle. When you do not want to use it, connect it to a magnet coil or resistance of some kind.

Its Chemical Action.—The zinc is dissolved by the sulphuric acid. The hydrogen thus liberated steals some sulphate from the copper sulphate solution. This frees the copper, which is plated on the copper electrode. In this action the zinc is dissolved and the copper is plated. The zinc disappears and the copper grows.

Its Electrical Action.—As atoms of zinc leave the zinc electrode to join the sulphate, they leave two electrons behind.

When the sulphuric acid was split, at the time you diluted it with water, the sulphate took two extra electrons, leaving the hydrogen with a lack of electrons. These hydrogen ions wander towards the copper plate, and passing through the copper sulphate, stop, look and think. They then sneak up behind a copper sulphate and steal its sulphate from it. The stolen sulphate, with its two electrons which it always takes when it leaves anything, gives the hydrogen a satisfied feeling.

But there was a copper associated with the sulphate before the sulphate deserted the copper and went with the hydrogen. This copper had two electrons taken away from it by the sulphate. Hence the copper attaches itself to the copper electrode and takes two electrons from *it*.

In this way, the action of the cell is continually piling up electrons in the zinc electrode, where they are crowded out to do work. The cell is also taking electrons away from the copper electrode, thus giving it an ability to pull electrons in out of the wire attached to the copper pole.

Throughout this action, no hydrogen gets near the copper electrode, where it would stop the electrical action and thus polarize the cell.

Electromotive Force.—Electron-motive force would better describe what is meant by the term electromotive force. Some cells create a greater pressure to move the electrons than others. These are said to have a high electromotive force. This is abbreviated as "e. m. f.," and quite frequently written in capital letters as E. M. F.

A cell that pushes well, but that is partly polarized, will have a low e. m. f.

VOLTAGE.—Electricians have agreed to use the term e. m. f. for the electron-motive force of a cell or dynamo when it is ready to deliver electrons but not doing it. A cell standing on your table before you close the circuit, and hence before the electrons begin to flow, is in this condition.

The electron-motive force developed while electrons are actually being moved is called the voltage. The abbreviation is "e." or "v."

POTENTIAL DIFFERENCE.—Electrons flow from one place of high pressure or high potential, as it is sometime expressed, to a place of lower pressure or potential.

When an instrument called a *voltmeter*, which is a galvanoscope with a coil in series with it, is connected by two wires to two places where the pressure is different, it shows the *voltage*. This means the pressure pushing electrons between these places. This is also the *difference in potential* between the places. These two terms mean the same thing. For this reason, electricians speak of the voltage or the p. d., the latter being an abbreviation for potential difference or what is the same, difference of potential.

E. M. F. OF CELLS.—The electron-pushing force of a cell depends on the materials used. Carbon and zinc make the best combination for a reasonable expenditure of money.

VOLTAGE OF CELLS.—Some of the e. m. f. of a cell

is used up in transferring the electrons across its own electrolyte. What is left is the voltage of the cell.

Expressed in a rather inaccurate but wonderfully helpful way, we might say that: the e. m. f. is the voltage when the cell *is not* furnishing current, and the voltage is the e. m. f. when the cell *is* furnishing current.

Resistance of Cells.—Every cell offers some opposition to the passage of electrons. This resistance is lowered by using large electrodes, placing them near together, and using an electrolyte furnishing many ions for carrying electrons across it.

Notice that the less the resistance, the nearer the voltage is to the e. m. f., because less pushing force is used up in the cell.

Quantity of Electrons Obtained.—The current or flow of electrons from a cell depends upon how fast the zinc is dissolved, how much the flow is impeded by the resistance of the cell and what its voltage is.

Please note that, primarily, the current depends on the weight of zinc dissolved per hour. It is this action that puts electrons on the negative pole of the cell.

Batteries.—A group of cells connected in any proper way is called a battery. A radio A battery is usually composed of three storage cells in one box. A bell ringer battery consists of several dry cells in a case. The radio B battery is a group of 15 small dry cells in one casing sealed up in a cement, so that only the terminals of a few of the cells show.

Types of Cells.—Since cells are used for so many different kinds of work, it is natural that certain types have been developed and improved for a definite kind of job.

High Voltage Cells.—The storage cell is the best. The average voltage is 2 volts. The bichromate cell will give 1.8 volts.

Low Voltage Cells.—While this is not a desirable feature, it is well to know that the Crowfoot and

Lalande cells are poor pushers. Their other very desirable qualities make us overlook the 1 volt pressure of the Crowfoot cell and the 0.7 volt pressure of the Edison type, Lalande cell.

LARGE CURRENT CELLS.—The storage cell and the bichromate cell lead in the large current, high voltage class. The Edison-Lalande cell furnishes more current at low cost of upkeep (replenishment and repairs) than other types. Its voltage is low.

LOW CURRENT CELLS.—Not a quality to desire, but the Crowfoot cell won't furnish a large current, and we like it just the same. The reason will appear very shortly.

WET CELLS.—A most annoying feature of all cells but the dry cell is the corrosive liquid which forms the electrolyte.

Clothing, floors and rugs will be ruined by contact with the chemicals in these cells.

DRY CELLS.—The cell shown in Fig. 25 B contains no liquid to slop around. A zinc can is the negative electrode. The electrolyte is a paste of sawdust, gelatin, ammonium chloride, zinc chloride and plaster, with enough water to make it moist. The better, and more expensive cells, have zinc oxide in the paste.

Around the carbon plate the paste contains black oxide of manganese. This turns the hydrogen liberated by the cell's chemical action into water.

The cell is sealed with a cement to prevent evaporation of the liquid and make the interior of the cell dry.

A good dry cell is indeed a good cell. Of moderate voltage, about 1.5 volts, it will furnish a moderate current, polarizes slowly, recuperates rapidly, and its resistance is so low that it wastes very little of its e. m. f. inside of itself.

OPEN CIRCUIT CELLS.—All the cells except the Daniel and the Crowfoot give better results on intermittent work. Any of them may be used for an hour or two,

but need a long rest after use in order that they may thoroughly depolarize themselves.

None of these cells would operate steadily for a whole night of twelve hours without being a badly used up cell the next morning.

Open circuit cells are those which work best and last longer without repairs, when the current is taken from them at intervals with rather long rests between.

Closed Circuit Cells.—When a burglar alarm or a signaling device must be supplied with current for 12 to 24 hours per day, we use Daniel or Crowfoot cells. These two are really the same cell, except that the Daniel, which has a porous cup to separate the liquids, is going rapidly out of use.

Not only will the Crowfoot cell work 24 hours a day, but you must draw current from it all the time. If you let it stand idle, furnishing no current, you will have trouble. The blue solution of copper sulphate will rise, and when it touches the zinc it will copper plate it. You then have two copper plates in the cell; it is polarized and will not push electrons.

When used on a burglar alarm the battery is, during the day, switched over to another circuit. This circuit is a coil of wire of such conductivity that a small current will flow, not enough to use up much zinc, yet enough to keep the blue copper sulphate at the bottom.

Primary Cells.—The cells which I have been describing are called primary cells. When the zinc is consumed, a new one is purchased and placed in the cell. When from long use the cell is dirty from impurities in the chemicals and dust which has fallen into it, the pressure may keep up but the zinc is now used wastefully. You do not get as many electrons per second as when the cell was new.

The cell must be taken apart, the electrolyte thrown away, jar washed out, new electrolyte put in, the carbon boiled in water and returned to the cell, the zinc

amalgamated, and the cell with the zinc in place is again ready for service.

SECONDARY CELLS.—There is another type of cell called a storage cell, sometimes referred to as a secondary cell. These cells are charged with chemicals and an electrolyte by their manufacturers. They furnish current, but like the primary cells their chemicals become exhausted. Since there is no zinc electrode in these cells, the negative electrode does not disappear. It changes, however, to a new and useless chemical.

When such a cell becomes weak we do not buy new chemicals and make the cell over again. Passing a current of electrons through the cell reforms the chemicals to what they were before.

Do not make the mistake of thinking that current is stored up for future use. The current makes chemicals which will go into action and produce a flow of electrons, just as in a primary cell.

Storage Cells.—The common term for such cells is a storage battery. One cell has such a low pressure that we use them in groups to get pressures of 6, 12, 32 or 110 volts, depending, of course, on the character of the job for which they are used.

THE LEAD-ACID CELL.—This type of storage cell, which is usually called the lead storage cell, is the kind used in electric trucks for power and in automobiles for starting the motor and operating the lights. It is also used in the private electric light plants now so frequently used in country homes. The action will be best understood after doing an experiment.

Experiment 24.—In a small jar mix sulphuric acid with five times as much water by pouring the acid into the water. Cut two plates of lead half as wide and as high as the jar. Solder wires or binding posts to them.

Soldering to lead requires that the soldering copper be just hot enough to melt the solder. Scrape the lead until it is bright and use rosin for the flux.

Should lead plates be hard to obtain, use lead pipe, sawing off pieces as long as the height of the jar.

Place the lead pieces in the jar of diluted sulphuric acid very close together. Should they be difficult to keep apart, place between them a sliver of wood.

Using Fig. 28 as a guide, connect the cell just made, C, with the galvanoscope and its shunt G, a switch S,

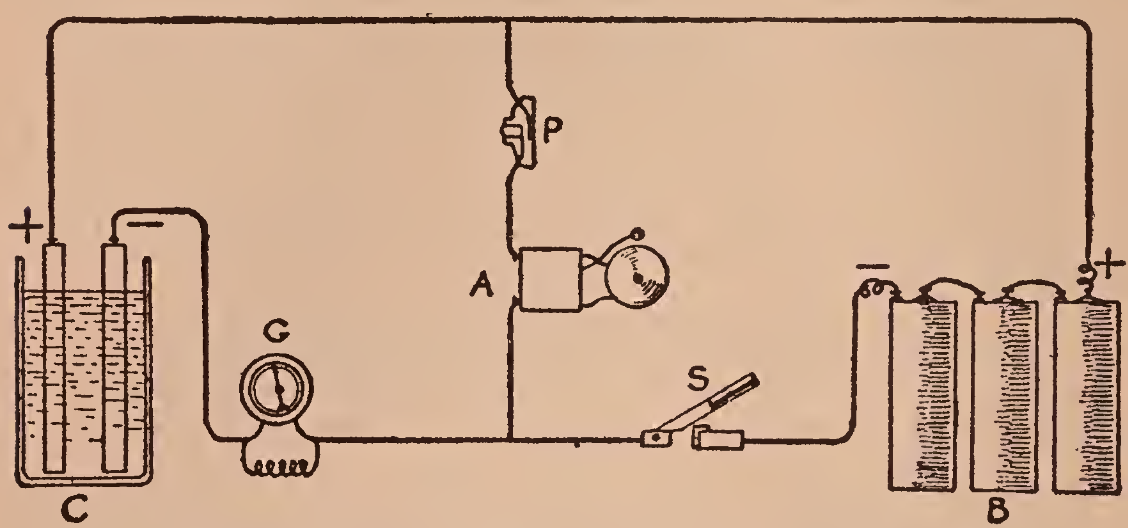

FIG. 28. AN EXPERIMENTAL STORAGE CELL.

three or four dry cells in series, B, and by a wire back to other pole of C.

The portion of the circuit that contains the push button P and the electric bell A can be soldered to the wires already in use or clipped on by the clips sold by radio dealers.

Right here we must come to an understanding about which way the current flows. All the books published up to date talk about the current flowing from the positive to the negative poles.

The authors of these books know that the electrons flow from the negative to the positive pole. They are often very careful to tell you that our usual way of talking is wrong, but that folks have become so used to that way that changing is scarcely worth while.

I agree with this. Probably for another ten years we will be talking about the current flowing a certain way yet knowing that the electrons flow in the opposite direction.

Whenever I say the current flows I shall mean in a direction opposite to the flow of electrons. When I say the flow of electrons is in a certain direction I shall be telling the exact truth.

During a certain transition period you will hear me and others say that the current flows out of the positive pole of a cell and that the electrons flow out of the negative pole.

For the remainder of the book watch sharply to see whether I say current or electrons before deciding that I have made an error in my explanations or our pictures.

Experiment 24 *Continued.*—Close the switch S. If you have no switch use a push button and lay a heavy book on it to keep it down. The electrons which leave the negative pole of the battery B enter the cell C and find both lead plates have a thin coating of lead sulphate on them. They naturally would, since they have been standing in sulphuric acid.

At the electrode where the electrons enter the electrolyte (the sulphuric acid), they cause the sulphate to enter the electrolyte. This leaves an electrode of pure lead. The sulphate entering the electrolyte splits the water there, taking the hydrogen to form sulphuric acid. The oxygen from the water goes to the other electrode and forms oxide of lead. This is a chocolate colored chemical.

The passage of electrons through the cell has done chemical work and the results are:

1. An electrode of pure lead.
2. More sulphuric acid in the electrolyte than when the electrons started to pass through it.
3. An electrode of lead oxide.

Chemists would call it peroxide of lead, for there are several oxides, each having a different color.

After five minutes of charging the cell, open the switch S. The storage cell has now a lot of electrons sitting on the lead plate, because as soon as you stopped charging, there stood a primary cell, made by electricity, but a primary cell just the same.

Press down on the push button P, and the bell A will ring. The cell C will drive out the electrons and keep up the pressure to drive them until its active chemicals are exhausted.

I really should say, until both plates are turned into lead sulphate. Since two materials of the same kind will not form a cell, two plates of lead sulphate or covered with lead sulphate, are worthless as electron pushers.

Repeat this experiment, watching the indications of the galvanometer. While charging, the current went one way, and during the discharge, while ringing the bell, it went in the opposite way.

For this reason, to charge a cell we connect the positive pole of our supply to what will be the positive pole of the storage cell.

The jar of a storage cell is usually made of composition, hard rubber, or specially treated wood. Fig. 29 shows a glass jar, which is sometimes used. This single cell has two negative plates with a positive plate between. This cell has a low capacity. More capacity is gained by using more positive plates, alternating with negative plates.

The last positive plate has an extra negative plate placed beside it. The first and last plates are always negative plates. Positive plates charged on one side only are apt to bend and thus loosen the chemicals deposited on them.

The Practical Lead Cell.—The cell of Fig. 29,

with perhaps larger plates and surely more plates, has cedar wood insulating sheets between the plates. These separators prevent the chemicals falling out of one plate from touching the other. They are porous, so that the acid soaks through, and electrons move through

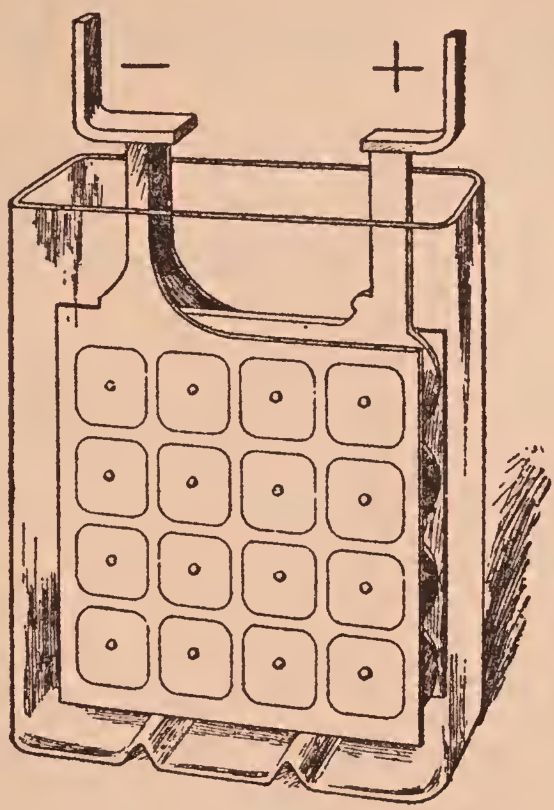

Fig. 29. A Lead Storage Cell.

them freely. The positive plate is chocolate colored and the negative plate grey.

The Alkaline Cell.—A cell perfected by Edison consists of nickel plated steel plates that are merely supports for the electrodes. These are formed in little cages of nickel steel, perforated to allow the electrolyte to penetrate the materials.

The negative electrode is pure iron, and the positive electrode is nickel peroxide. The electrolyte is a 20 per cent solution of caustic potash.

This type of cell will stand much rougher electrical treatment than a lead cell. For the same capacity for work the Edison cell is half as heavy as the lead cell.

Using Storage Cells.—Lead cells should be renewed by sending current into them until each has an e. m. f. of 2½ volts. You may use them until the pressure of each cell has fallen to 1¾ volts. You must not use them any longer, as injury to the plates results. Over charging too much and too frequently injures the plates. Discharging to a completely empty condition also injures the plates.

Follow the directions which come with a storage battery and it will give you good service. Remember that the denser the acid by a hydrometer test, the greater the charge in the cell.

An Edison cell is charged up to a pressure of 1⅓ volts. It can be charged and discharged at almost any rate. A lead battery must be charged and discharged at rates not greater than those given in the instructions which come with the battery.

Sizes of Batteries.—A battery is made up of cells, usually made up in a block with but two terminals showing. A lead type 6 volt battery contains 3 cells.

Each of these cells contains enough plates so that the energy stored up may be sufficient to send a current of so many amperes for so many hours.

A 60 ampere-hour battery will furnish 6 amperes for 10 hours or 3 amperes for 20 hours. I am quite sure that 12 amperes for 5 hours would injure the plates chemically and also buckle or bend them, due to severe and unequal heating.

An ampere-hour is one ampere for one hour, or its equivalent.

A 3 tube radio set may draw 3 amperes from the battery. Used for 2 hours it is using 6 ampere-hours. At this rate a 60 ampere-hour battery would last 20 hours, after which it would be polarized and need recharging.

CHAPTER VII

MEASURING ELECTRICITY

NEED FOR MEASURING
- The Electron
- The Coulomb
- The Ampere
- The Ohm
- The Volt
- The Farad
- The Henry
- The Watt
- The Kilo-Watt
- The Kilo-Watt Hour

COMPUTATIONS

CIRCUITS
- A Dead Circuit
- A Live Circuit
- The Ground
- A Series Circuit
  - Shunts
- Short Circuits
- Parallel Circuits
- Series Parallel Circuits

THE FLOW OF CURRENT
- Power

THE WATER ANALOGY

THE ELECTRICAL CIRCUIT
- Balky Cells

THE IMPORTANCE OF OHM'S LAW

OHM'S LAW
- Problems

DIVIDED CIRCUITS
- Combined Resistance
- Rules for Computations
  - Problems

AN OLD ERROR

CURRENTS IN DIVIDED CIRCUITS
- Experiment 25

CHAPTER VII

MEASURING ELECTRICITY

Need for Measuring.—Electricity could not be sold without definite units of quantity. Since work is accomplished by the quantity of electrons arriving at the job, but is accomplished the more quickly the faster these electrons arrive, we also need a unit combining these two factors.

We need a unit for the pressure with which electrons arrive at the place where they do work.

Since electrons are sometimes temporarily stored up in condensers, we need a unit for the capacity of things. Remember that we cannot store amperes, for they are electrons in motion.

I have not discussed these units yet, because one can do a lot with electricity without measurements. However, it is time that you know what these units are and their names, even though you do not personally intend to measure anything electrical.

The Electron.—This is the tiny speck of negative electricity that measures all charges and currents. When an electron passes through a place it does some kind of work. It may heat, give magnetism, cause light, electro plate metals, dissolve metals, or it may itself take a flying leap from its conductor.

We have selected a certain kind of work to determine the number of electrons working on a job. Whenever, in an electroplating bath of silver nitrate solution, we find that 0.001118 grams of pure silver have been plated, we say one *coulomb* of electricity has passed.

The Coulomb.—We use the word coulomb as an

abbreviation for 6,300,000,000,000,000,000 electrons. While the electron is the actual unit, the coulomb is the practical unit. In the same way a stalk of asparagus is the actual unit of eating, but a bunch is the convenient unit in purchasing.

THE AMPERE.—The more coulombs arriving each second, the sooner we will get our work done. If we had one word for *a coulomb per second* we could talk with greater brevity. We borrowed a word for this, taking a scientist's name. The *ampere* is that flow of electrons which amounts to 1 coulomb passing a point in the circuit every second. It was named after André Ampère.

The practical method of determining an ampere is by use of a silver plating bath. When 0.001118 grams of silver are plated per second, then a current of one ampere is flowing.

To find the current in a circuit a silver plating bath is inserted in the circuit so that the current will flow through it. The current is allowed to flow. Then the weight of the silver plating on the negative wire, divided by the number of seconds that the current flowed, and also divided by 0.001118 will give the current in amperes.

You are perhaps thinking that this is a very difficult and tedious operation. Yes this is true, but we do not know of any method that is as accurate.

If you will consider the following experiment you will understand the situation, and have a keener realization of the difficulty in getting an accurate measure for current. When I say an accurate measure, I mean also some effect that increases regularly as the current increases.

Suppose as in Fig. 30 we had a circuit in which were a galvanoscope, an electromagnet, a silver plating bath, a lamp and a heater. The heater will be placed in a box, which will be surrounded by water. A

thermometer in the water will indicate the temperature caused by the heater.

Connect this circuit to a source of power and when the current is flowing you will observe that: the needle of the galvanoscope is deflected, the electromagnet will support weight, the silver will be plated on the negative wire of the plating bath, the lamp gives

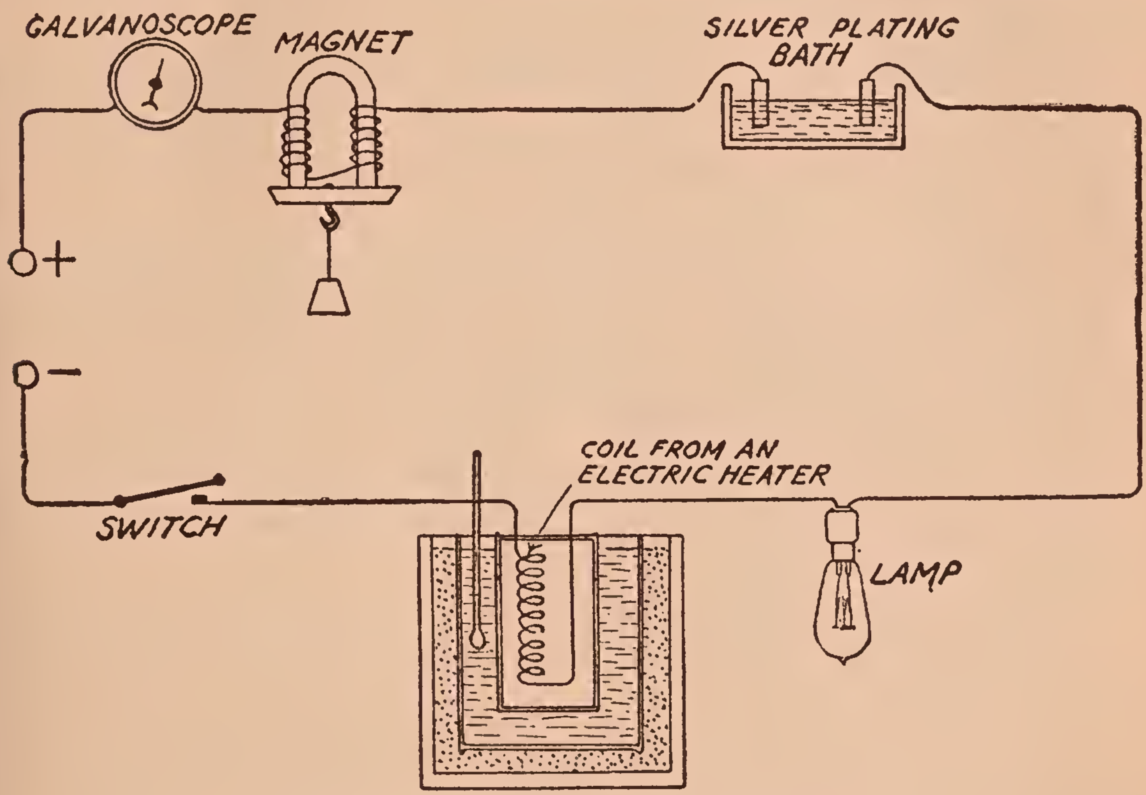

Fig. 30. The Effects of Current.

light, and the thermometer shows that the temperature of the heater is increased.

We now must observe closely the size of the different effects when the current is changed to twice and then three times its original value.

The galvanoscope gives deflections of 2, 3 and 3.4 scale divisions. Hence equal increases in the current do not give equal increases in the deflection.

The electromagnet supports 9 lbs. then 11 lbs. and finally 11.5 lbs. So the strength of a magnet does not increase in the same proportion as the current.

In the plating bath there is deposited; at first 4.025

grams per hour, then 8.05 grams per hour and finally 12.075 grams per hour. Here we have an effect that is exactly in proportion to the size of the current.

Let us see if the two remaining effects may be of value for measuring current. We are disappointed.

The lamp is worthless as a method of measurement. At first the increase in light was startling and then the filament burnt up.

The heater at first caused the thermometer to rise at rate of 1/10 of a degree a second, then at 4/10 degrees a second and finally at the rate of 9/10 degrees per second.

Looking over the effects of increasing the current to twice and then three times its original value, as shown by these instruments, you see that only the plating bath gave a regular and simple indication.

The electro plating effect is equal for equal increases of current whether this is the first increase or the last of many increases.

This is one reason the plating bath is the scientist's instrument for the accurate measurement of current.

The second is, that we may obtain balances, perhaps you would call them scales, that will weigh the ten thousandth part of a gram. Hence the silver deposited may be weighed with great accuracy.

THE OHM.—Every material offers some opposition to the passage of electrons through it. We need a certain piece of material as a standard resistor and a name for it.

A column of pure mercury 106.3 centimeters long, enclosed in a glass tube of 1 square millimeter inside area, is placed in melting ice. The resistance of this to the passage of electricity is called an *ohm*. This unit was named after George Ohm.

Since the resistance of a material changes with the temperature, unless a particular temperature is stated we have an indefinite unit.

The temperature of melting ice is easy to obtain and is always the same. Hence it was adopted for this and for many scientific standards, as the temperature at which the measurement is to be made.

The Volt.—There must be a unit of electron-pushing power, that is of e. m. f. What we call voltage will be measured by this unit. The pressure which will cause one ampere of current to flow through one ohm of resistance is called a volt. This unit is named after Alessandro Volta.

The Farad.—Condensers really hold electrons or big groups of electrons called *coulombs*. If a condenser could hold one coulomb when the tendency of the electrons to jump through the insulation is just one volt, then we say the capacity would be one farad. This unit named after Michael Faraday is so large that a micro-farad (one millionth of a farad) is our every day unit. Electricians call them "mikes." So now you know what a "one mike condenser" means. Also that directions to buy a "triple oh five condenser," really means to buy a condenser with a capacity of .0005 micro-farads.

The Henry.—When the current in a coil of wire is increasing or decreasing, the coil resists the change. The coil is conservative, dislikes any change in the current through its wires, and produces an e. m. f. trying to stop this change. We say a coil has *inductance.*

When an increase of the current by one ampere in one second causes the coil to develop a 1 volt pressure trying to stop us, we say the inductance of that coil is one *henry*.

This unit was named after Joseph Henry of Albany, N. Y., who discovered inductance in 1830.

The Watt.—What we folks want is the necessary work done in the least possible time. Each electron will do a certain amount of work. High pressure or

voltage behind the electrons does not increase their speed. This is fixed by nature at 186,000 miles per second. Heat, light, electricity and radio all travel at this same speed. The voltage does increase the number of electrons arriving. It also gives them a pushing and shoving ability.

The work done depends on the amperes and the voltage, that is on the quantity of electrons per second and their pushing power. Thus the unit for measuring power is a combination of one ampere at one volt pressure and is called a *watt,* named after James Watt.

THE KILO-WATT.—A watt is large enough for many measurements. For example:—writing this by the illumination furnished by a 50 watt Mazda lamp, I get an idea of what 50 watts of power will do.

In the last few months the Electric Company has been sending me so many amperes at 110 volts pressure that the word watt represents too small a unit. We then speak of *kilo-watts,* each of which equals 1,000 watts. Kilo means 1000.

THE KILO-WATT HOUR.—You will agree that if the Electric Company serves me at the rate of one kilowatt, they should be paid in proportion to the number of hours they do it.

For this reason, the meters which determine our electric bills, register the result of three things 1—amperes, 2—volts, 3—time in hours. The combination of 10 amperes at 100 volts for 1 hour, or any combination amounting to the same ability to do work will be called a *kilo-watt hour.*

Computations.—I think you will agree with me when I say that the ability to handle electricity intelligently, to make the front door bell ring again when it takes a vacation, to operate and perhaps make a radio set, is to be attained before you bother with problems in computation.

The next thing will be to understand why the

familiar electrical things work. This is not a matter of arithmetic. It has to do with the nature of things, not their quantity.

There are a few rules that you may wish to know about, but you must know more about circuits and what happens in them, before you tackle the rules.

Circuits.—The path through which the electrons pass may include wire instruments, machinery, vacuum tubes, heaters and such devices. It is called a circuit because the electrons make a circuit back to their starting point. *Line* is a slang word for circuit.

The word circuit is used with many others, and so we have series circuits, parallel circuits, shunt circuits, short circuits, etc.

A Dead Circuit.—Before a switch has been closed to connect a circuit or line to the battery or the dynamo, there is no current in the circuit and we say that it is dead.

A Live Circuit.—Suppose that in a power house a generator is running at full speed and that no wires are attached to its terminals. No current flows but the full pressure or e. m. f. is at the terminals.

Wires may be attached to this generator and brought through the streets to your room ending there in an empty lamp socket. Pull the chain or push the switch or do whatever in your home would light the lamp if it were in the socket.

Electrons will flow along the wire to this socket and there stop, for there is no complete path, there is a gap in the circuit. There is no current flowing now. There was at first a rush of electrons but when that was over there was no more movement of electrons.

Such a circuit we call a *live circuit.* Should you remove both fuses from the house supply wires, then your wiring will be *dead,* but the wires in the street will be *live.*

Beware of the open place or the gap between the

wires of a live circuit. Should you bridge this gap with your body, or should you touch twc points near in feet but electrically, far from each other, you will receive a shock. This shock may be a mere trace of feeling, a tingle or a serious shock, depending upon the voltage applied to the line. A radio set, with four blocks of B batteries in series, will give you a shock that you will remember, provided that you touch the wrong places. Ninety volts have some kick to them, especially if your hands are damp.

THE GROUND.—When one part of a circuit is composed of copper wire and the remainder of railway

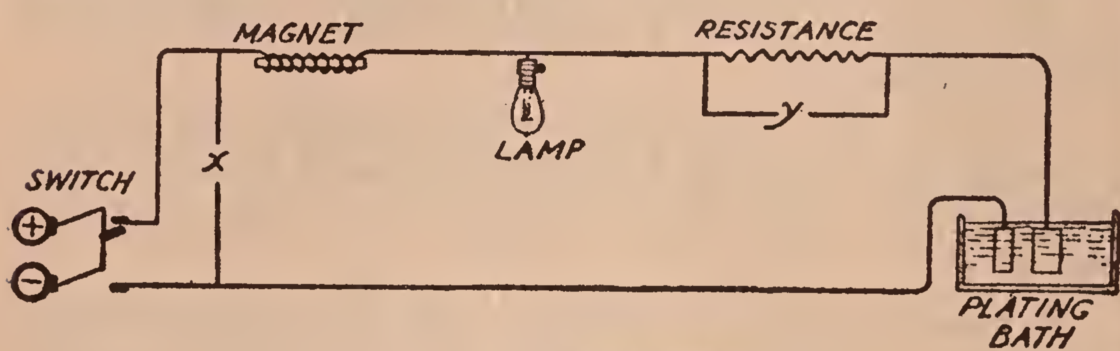

FIG. 31. A SERIES CIRCUIT.

rails, water pipes, or the earth, we speak of the copper part as the line and of the remainder as *the ground.*

Your radio set may be connected to *the ground.* This means that you are using the air and the ground as a means of leading the radio waves to your set.

A SERIES CIRCUIT.—An inspection of Fig. 31 will show that a series circuit is one in which the same electrons pass through every wire and device in the circuit.

Starting at the source of power the wires go to a double pole switch. When this switch is open the circuit is *dead.* If a single pole switch were used one side of the circuit would be *alive* all the time.

When the switch is closed the current flows through the magnet, the lamp, the resistance and the electroplating bath, for they are all in series.

In such a series circuit, the same current must pass through each piece of apparatus. The lamp requires 1/3 of an ampere. The electro plating bath 10 or more amperes. It is evident that a series circuit is not adapted for serving different kinds of apparatus.

Suppose all the lamps in a house were on a series circuit. When one lamp is to be turned out or shut off, the circuit must be opened. Then all the lamps go out.

In series circuits we may divert nearly all the current around a certain place by using a *jumper* or a *shunt.*

Shunts.—At y in Fig. 31 is shown two wires which when joined will carry some of the current around the resistance. If the resistance of the path through y is low, most of the current which before went through the resistance will now go through this new path.

A low resistance path such as has just been described is called a *shunt.*

The wires at x when connected make a shunt. But this kind of a shunt forms a path around all the resistance of the circuit.

The laws of nature are such that a small resistance means a large current. Hence if the shunt at x is completed such a large current will flow as will over heat the wires, perhaps even melt the solder on the joints in the wires.

Any path of low resistance, which causes a very large current to flow is called a *short circuit.*

Short Circuits.—These are usually short in length and very low in resistance, causing dangerously large currents to flow.

Keep metal tools away from circuits, lamp sockets and storage batteries. Never try to repair any electrical device unless it is removed from the source of power. Since lamp sockets can't be removed, before fussing with them, personally remove the fuses in that cir-

cuit. Until you are quite expert, leave jobs on the house wiring to electricians. It is better to be safe than sorry.

Parallel Circuits.—In order to bring the source of power to each device used and thus make them independent of each other the hook up of Fig. 32 is used.

In this arrangement each piece of apparatus may be connected or disconnected, without affecting the others. This is the arrangement of the lamps in our homes.

A low resistance connected at x or anywhere on the circuit, as at y, produces a short circuit. Do not

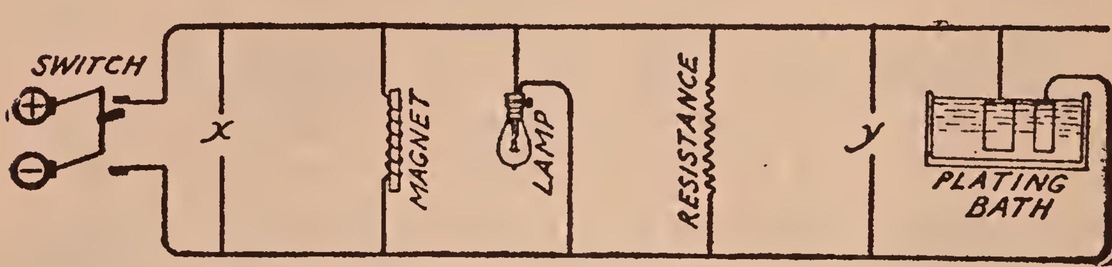

Fig. 32. A Parallel Circuit.

connect any device to the wiring of your home until you are sure that it will not cause a short circuit. Electrical toys and experiments should never be connected to the house wiring. Look at Fig. 6. Read the explanation of it. Then attach your experiments or toys to the proper safety device and attach that to the house wiring system.

Series-Parallel Circuits.—When each part of a set of parallel circuits contains several pieces of apparatus in series, we have a series-parallel combination.

The lights of a trolley car are arranged in this way. In order to push the electrons the long distances the voltage applied to the trolley wire or the third rail must be larger than that used for house lighting. It is usual to have an e. m. f. at the power station of from 550 to 750 volts.

Suppose the average voltage in the cars of a trolley

road to be 550 volts. If the same type of lamp is used in these cars as is used in your home, then the 550 volts would send through one of these lamps, designed for use at 110 volts pressure, a current 5 times as large as it was built to carry. The lamp would

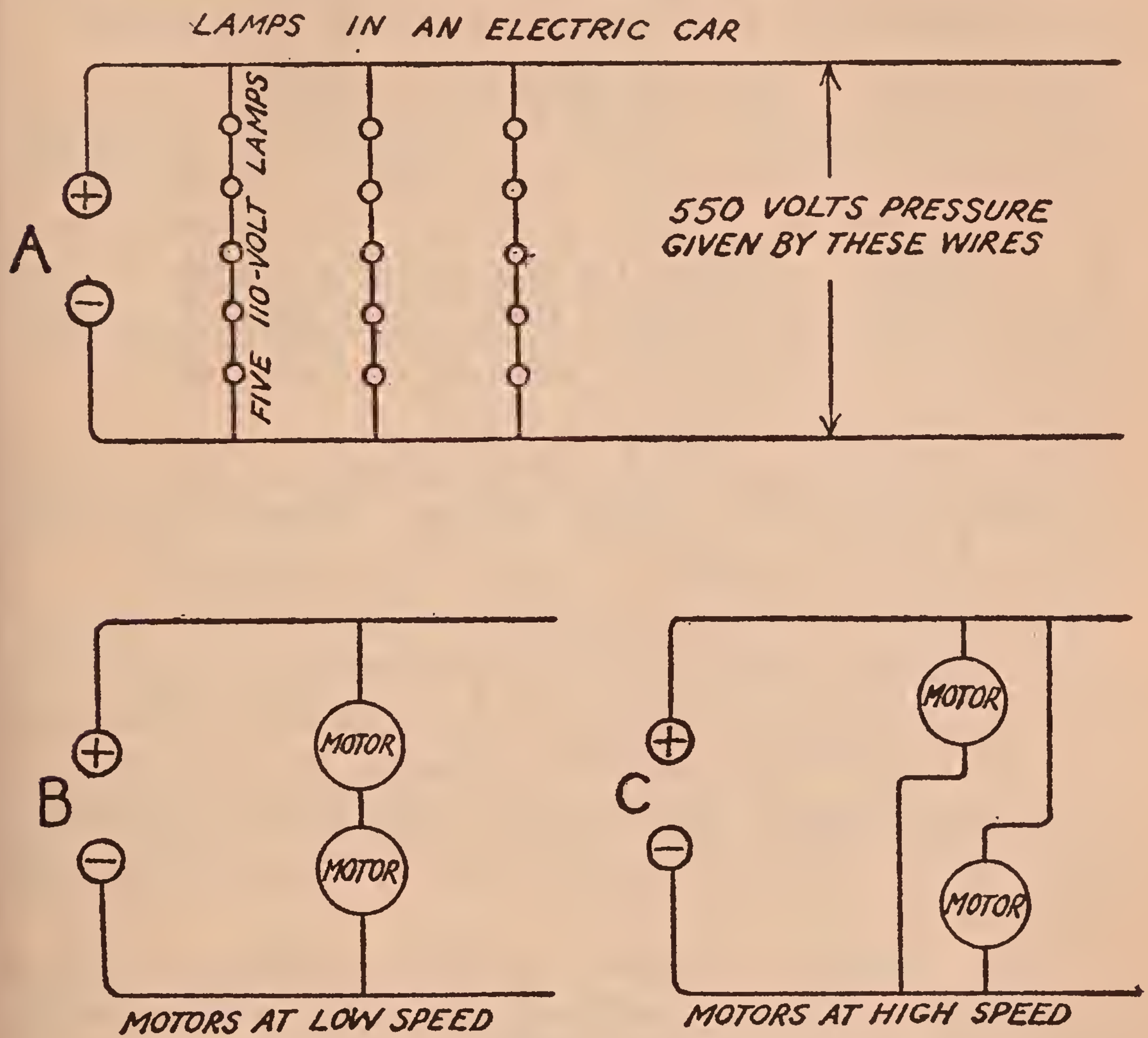

Fig. 33. Series-Parallel Circuits.

burn brilliantly for less than a minute and then the filament would melt.

This could be avoided by making a special lamp, sturdy enough to stand up against the 550 volts, but this would be very expensive.

If however, 5 lamps were arranged in series the set would be able to stand 550 volts. Now refer to Fig. 33A and notice that each set of 5 lamps in series is

connected to the feeding wires in parallel. In this way each set of 5 lamps is subjected to 550 volts, yet each set of lamps is independent of the others.

Should any one of the 5 lamps of a set burn out, the whole set will go out.

In many electric railway cars, over the doors and on the platforms, are lamps which only light when the trolley or third rail shoe gets out of contact with the feeder wire or rail. These are operated by a storage battery and thrown into the circuit of that battery by an automatic switch. This switch is held open by a magnet operated by the current going to the motors. When this current fails, the magnet is demagnetized, the switch lever is allowed to fall, and the circuit of the storage battery is closed.

When the motors get current again, the switch lever is pulled up and the circuit broken. These lamps are special lamps designed to run on low pressure.

Speaking of motors, reminds me that the two motors of an electric railway car are connected in series to start the car and to run it at low speed. When the car has attained the greatest possible speed with the series arrangement, then the two motors are connected in parallel. These connections are shown in Fig. 33 at B and C.

These changes are made by the controller. This is a rotating cylinder carrying switches which make, break and rearrange the circuits.

As the motorman turns the handle the first movement arranges the motors as in Fig. 33B, then each of the motors receives half the voltage of the line and so they run at low speed. Thus the car is started without the wheels slipping.

Subsequently the motors are connected in parallel as shown in Fig. 33C. Each motor now receives the full voltage of the line and they run at their highest speed.

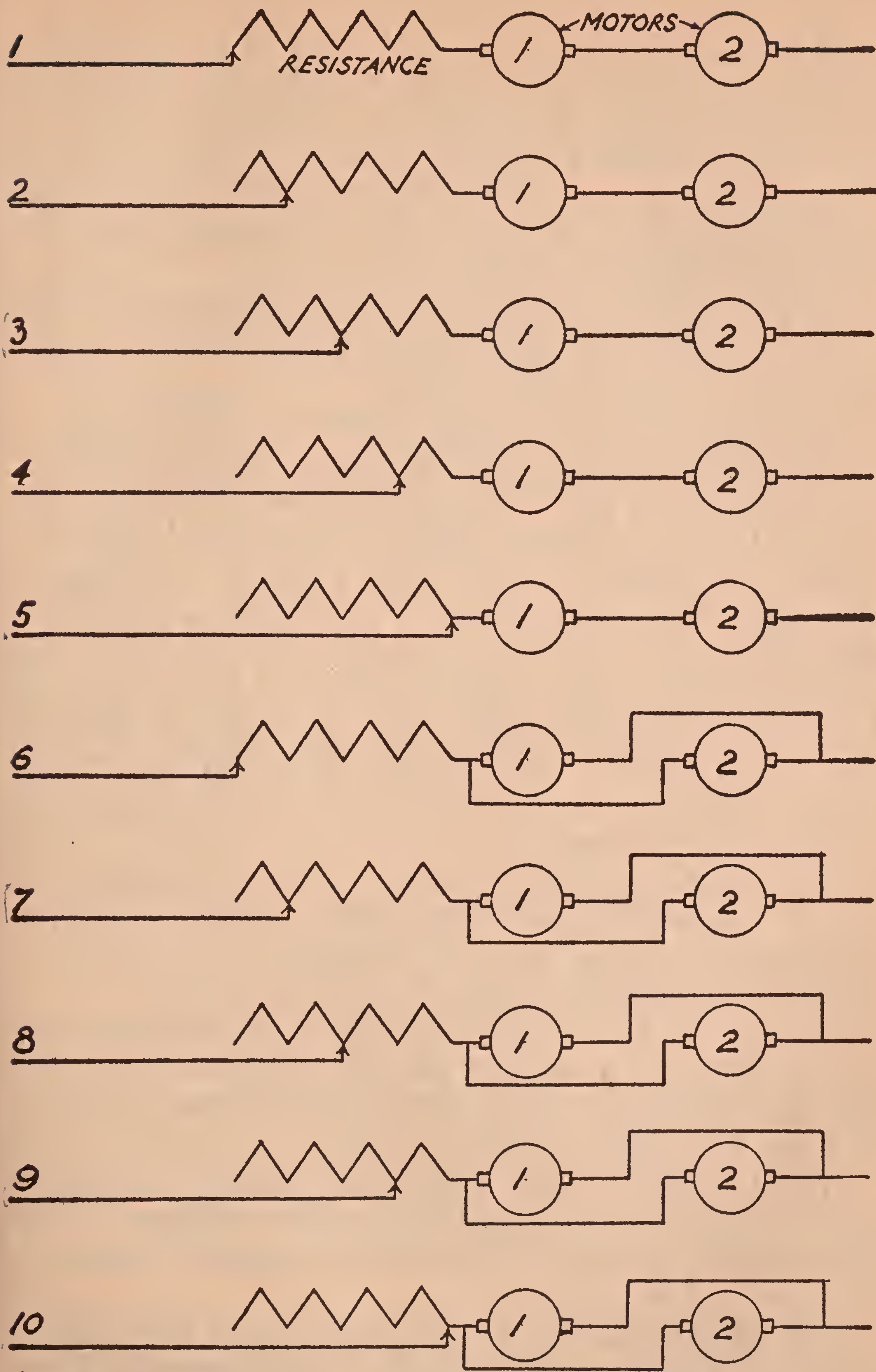

FIG. 34. SERIES-PARALLEL CONTROL OF RAILWAY MOTORS.

There is a resistance which is used to gradually increase the speed of the car. The way this resistance is connected into the circuits is shown in Fig. 34. You will see there how the resistance is cut out; how it is thrown in the circuit again as the motors are placed in parallel, and how again cut out to increase the speed of the car.

There would be ten positions of the handle of the controller while starting the car. In motorman's slang these positions are called *notches*.

The Flow of Current.—Now that you are familiar with circuits, let us consider how electricity flows through them. You know that certain devices pump up an electrical pressure. Have you noticed that the steam, pneumatic or hydraulic engineer is always worrying about the pressure. The indications of the pressure gauge are of the utmost interest and importance to him. Of course he does not like leaks, but not so much because they lose material as because they lose pressure. You see the steam, the air or the water would be of no use to him were they not delivered under pressure.

The electrical engineer wants a stream of electrons, but he wants them under pressure. In fact 5 million electrons will do the work of 10 million, if the smaller number are delivered at twice the pressure.

Power.—Since it is the quantity of electrons arriving per second and the pressure behind them that tells us what power there is for our use, the electrical engineer also talks a lot about *watts*.

A watt is not a thing that can be made by electrical cells or dynamos and sent out to the engineer. We must send amperes, with volts of pressure; the combination makes *watts*.

The Water Analogy.—We can get a very clear idea of the flow of electricity by considering the flow of water in a pipe.

When there is a current of water flowing, it is because there is a high pressure at one place in the pipe and a lower pressure at some other place. To say it differently the current is caused by a difference in pressure.

The current will be greater or less as this difference in pressure is greater or less, and this current will also depend upon the resistance offered by the pipe. If we desire to alter the current, we may open a faucet

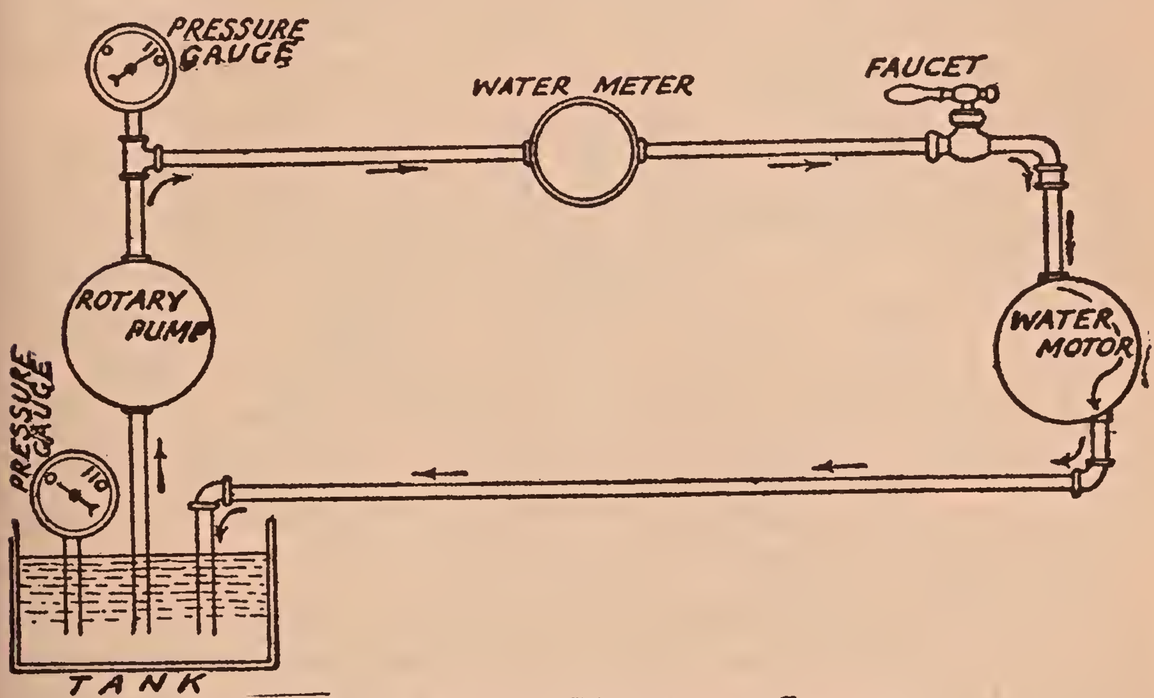

FIG. 35. A SIMPLE HYDRAULIC CIRCUIT.

more, thus lessening the resistance. We may also get an increased flow by telephoning to the Water Company and asking them to increase the pressure.

The flow of water is controlled by the pressure and the resistance.

The electrical engineer proceeds in the same way to find what pressure is available, and then he so alters his resistances as to cause the current he desires, to flow.

To make the analogy between a water system and an electrical system we must make a closed circuit in each case. In Fig. 35 is shown a closed circuit in which

water circulates so that there is no waste of water, for the same water is used over and over again.

The rotary pump takes in water from the tank, and gives the water a pressure so that it flows out with considerable force. The pressure gauge at the intake of the pump reads zero, but the gauge at the delivery pipe of the pump reads 110 lbs. per sq. in. This means that every square inch of any thing trying to oppose the water would feel a force of 110 pounds.

To the faucet, which is wide open, is attached a water motor. This motor drives a grindstone. The outlet pipe of the water motor runs to the tank.

Please remember that we are not generating water, we are simply putting the water which is already there into motion. The water meter will tell us the quantity of water which passes through the pipe to the motor.

The readings of the two pressure gauges show us what pressure the pump is furnishing. The difference between the readings of the two pressure gauges shows the force that causes the water to circulate in the conducting path that we have provided for it.

If a tightly fitting cover were put upon the tank and the water flowed from the motor with 10 lbs. per square inch pressure, then the pressure in the tank would be 10 lbs. per sq. in.

Since the pump can add 110 lbs. per sq. in. pressure to the liquid entering its inlet, then the pump would deliver the water at 120 lbs. per sq. in.

The difference in pressure would still be 110 lbs. per sq. in. and the motor would operate as well as it did before.

Returning to the case where the tank is open, as shown in Fig. 35, suppose we partly close the faucet. This increase in the resistance of the circuit to the flow of water will result in a lessened flow unless the pump is driven at a higher speed.

Pressing a knife upon the grindstone slackens the

speed of the motor. Now if it was an electrical motor it would draw more electricity and fight hard to keep up its speed and power. The water motor does not. So although thinking of water or hydraulic circuits helps you to understand electrical circuits, thinking of water motors will not help you at all in understanding electrical motors.

If we stop the pump the two pressure gauges will both read zero, and no work can be done. The same

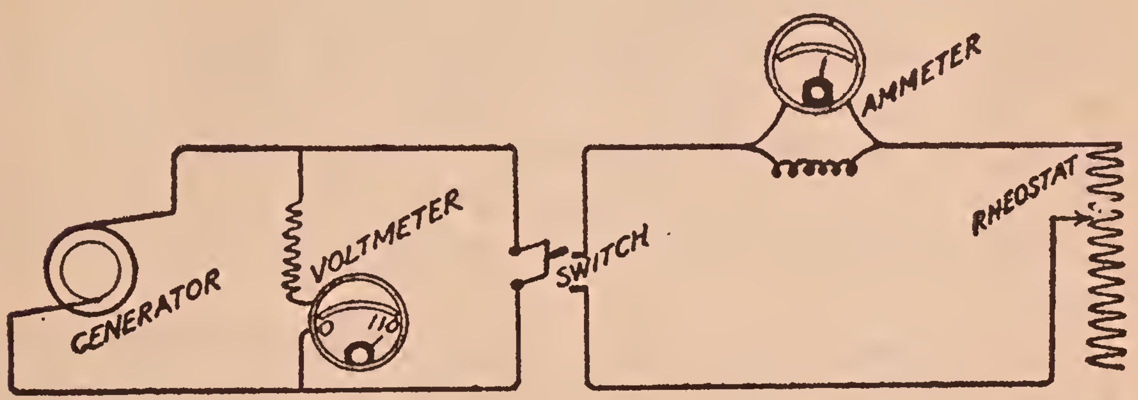

FIG. 36. A SIMPLE ELECTRICAL CIRCUIT.

amount of water will be there as before, but being at rest cannot do work.

Let us close the faucet and start the pump. Before, when the faucet was open the water could flow away from the pump. The pump had to push very hard on the water as it was flowing away in order to keep up a pressure of 110 lbs. per sq. in. Now the faucet is closed and the pump can, without working any harder, keep up a pressure of 120 lbs. per sq. in. at its delivery pipe.

All these things are simple, and they are quite easily understood. Keeping in mind that an electrical circuit has similar actions going on in it, we will now consider an electrical circuit. I am sure you will find that what happens in it may be readily and thoroughly grasped and tucked away in your brain for future use.

The Electrical Circuit.—After a parting glance at the hydraulic circuit turn to Fig. 36. Here I have made a complete circuit of copper wires and appliances which conduct electricity. I could use the earth in the same way as I used the tank in Fig. 35 as a storage place. We seldom do this in electrical circuits because the resistance of the earth is higher than that of copper.

It costs less to operate a circuit such as shown in Fig. 36 than one using the earth either as a conductor or a storage tank. Hence if we have enough money to build what is called a complete metallic circuit we do so. Frequently it pays to borrow the money to build a complete metallic circuit, for we repay the borrowed money out of the savings, in the operating costs.

In railroad work where years ago we used the earth as one conductor, we now use the regular train rails as the other conductor. We even go so far sometimes as to add to the conductivity of these train rails by running a copper wire in parallel with them. This means that the current has three metallic paths to follow on its trip back to the power house.

Looking at Fig. 36, let us start at the generator. Whether of the a. c. or d. c. type, it is merely a device for pumping electrons just as the water pump acted on the water. The generator pumps electrons by maintaining a difference in pressure between its terminals.

There are two wires attached to the circuit, one on each side of the generator. These wires lead the pressure at the spot where they are attached up to the voltmeter. The voltmeter reads the difference in pressure between these wires.

A voltmeter reads the difference in pressure between the two points in the circuit to which it is attached.

It seems as if the voltmeter actually subtracted the

pressures and indicated the answer. Notice that one voltmeter does for the electrician what two pressure gauges did for the hydraulic engineer.

We can get the pressure at a given place by use of an accurately constructed gold leaf electroscope, but we very seldom want this information. Since it is difference in pressure that causes electrons to flow we are glad that the voltmeter gives us this information directly.

Perhaps you have been thinking from the time of your first glance at Fig. 36, that the wires to the voltmeter and the instrument itself formed a circuit which robbed the main circuit of current.

It is true that the voltmeter circuit is a shunt and hence is in parallel with the main circuit. It draws away from the main circuit only about one hundredth of an ampere. Remember that a galvanometer to be used as a voltmeter must have a coil in series with it. We make the resistance of this series coil quite high. So little extra current is drawn by the voltmeter when connected to the circuit as a shunt, that in practical work we entirely disregard that current.

The amount of current is measured by the ammeter so placed that all of the current leaving the source is measured by it. Yes, some of the current does go through the shunt, but the galvanometer and its shunt together make the ammeter and this instrument is marked to give a reading that tells you what current is in the circuit of which the ammeter is a part.

The rheostat or variable resistance was placed in the circuit in order to regulate the flow of electrons, as the faucet regulated the flow of water.

While the ohms of resistance in a rheostat do not change, the effect of the rheostat does change as you move the rheostat from one circuit to another.

Once I was using a 10 ohm rheostat in a circuit with 5 ohms of wire and apparatus. Changing this rheostat

from 0 ohms to 10 ohms made a great change in the current. As I remember the results, I found I could change the current from 2 amperes down to 2/3 of an ampere.

A friend borrowed this rheostat and placed it in a circuit with a lamp. He wanted to make the lamp burn very dim and then bright. The lamp had a resistance of 330 ohms. The total resistance of the circuit changed so little with this rheostat in the circuit that the electrons found very little extra opposition.

When my friend returned the rheostat remarking that it was no good, that it scarcely changed the current, I told him that he had better learn Ohm's Law. In a few minutes that is just what *we* are going to do.

Suppose the generator in Fig. 36 to be revolving at its proper speed. The voltmeter reads 110 volts. A flow of electrons takes place throughout the circuit. These electrons were there before the generator was in operation. The difference in pressure serves to push them around.

If now we open the switch no current can flow and the volts that formerly pushed the electrons through the generator now are not used up in that way. The voltmeter now reads 120 volts. The e. m. f. in that circuit is 120 volts but the voltage on the circuit which we attached to the generator is 110 volts.

Balky Cells.—We now see why cells having a high internal resistance may show up 1.5 volts when the voltmeter is attached to them, but when used in a circuit give less than 1 volt.

Because some of the volts of a cell are always occupied in chasing the electrons through the cell itself. The remaining volts push the electrons through your wires and apparatus. The larger the current the greater is the number of the volts of the e. m. f. of a cell used up in sending the current through the cell itself

and the less left for sending the current through your toys and experiments.

It is the volts that get used up in pushing electrons through the circuit. The number of electrons moving is the same at all parts of a simple circuit.

The Importance of Ohm's Law. — One cannot use electricity much without wanting to know what current will flow when we do certain things. Often we must find out how many others will choke the current down to a certain number of amperes.

Sometimes when a circuit is set up, we know how many amperes must flow to operate the apparatus, we know how many ohms of resistance the circuit opposes to the e. m. f., and we must calculate how many volts are needed to send the desired current.

We can do all of these things by using Ohm's Law.

OHM'S LAW.—The current in amperes is equal to the difference in potential in volts divided by the resistance in ohms.

As a formula—

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

as often expressed using letters,

$$i = \frac{e}{r}$$

Problems.—A few problems will make the use of the law clear.

I.—I have two dry cells and a 5 ohm telegraph sounder. If I connect all these in series with a key, what current will flow?

You have two cells each with e. m. f. of 1.5 volts. In series they will add their voltages, hence the total e. m. f. is 3 volts.

The resistances opposing the flow of current are:

1. The resistance of the cells. This is about 0.1 ohm for each cell or 0.2 for the two in series.

2. The resistance of the wire used to connect the cells to the sounder. This is about 0.25 ohm.

3. The resistance of the contacts where the wires are connected to the binding posts and of the moving contact in the switch or key. This may be as much as 0.75 ohm.

4. The resistance of the sounder, which is 5 ohms.

All these resistances are in series and thus add their effects, making a total of 6.2 ohms.

Using Ohm's Law we find that the current in amperes will be—3 volts divided by 6.2 ohms which is 0.48 amperes. Thus we may expect a current of about ½ an ampere to flow in this set up.

II.—It required 5 dry cells in series to obtain a current of 2 amperes through the coil of an electromagnet. What was the resistance of the magnet?

The e. m. f. is 5 times 1.5 or 7.5 volts. The total resistance of the circuit is enough to make the current 2 amperes.

From Ohm's Law we see that the volts divided by the amperes give the resistance of the circuit. Since 7.5 volts divided by 2 amperes gives 3.75 ohms, the total resistance of the circuit is 3.75 ohms. But the cells offer about 5 x 0.1 ohm = 0.5 ohm, for they are in series.

When the resistance of the cells themselves, 0.5 ohm, is subtracted from the total resistance, 3.75 ohms, the result, 3.25 ohms is the resistance of the electromagnet.

III.—A 6 volt storage battery is connected to a radio receiving set using 4 amperes of current. The wires between them have a resistance of 0.2 ohm. What pressure will be delivered to the set?

From Ohm's Law we see that the volts required

to push a current through a resistance may be found by multiplying the amperes by the ohms.

Hence the voltage required to deliver the current to the set will be $4 \times 0.2 = 0.8$ volts. So the pressure at the set will be $6 - 0.8 = 5.2$ volts.

Before you leave this problem be sure that you understand that 0.8 volts was destroyed in pushing the electrons through the opposition offered by the 0.2 ohms resistance.

Divided Circuits.—When a 6 ohm coil and a 3 ohm magnet are connected in series the resistance is 9 ohms. When connected in parallel so that the current splits and goes through both, the resistance that they offer is lowered.

When two paths conduct the current the opposition is less than if there were only one. For this reason the effect of two resistances in parallel is to offer a resistance less than the resistance of the smaller of the two.

To gain a clear idea of these facts, we will consider first a simple circuit, one that may be in your home today.

A 110 volt supply from a generator serves a toaster which, offering 22 ohms resistance, has a current of 5 amperes flowing through it. Please do not say "Certainly, by Ohm's Law that is the current that must flow." Not at all. Since this voltage does send through this resistance 5 amperes by the laws of Nature, George Ohm could by patient investigation discover Nature's law. This value of 5 amperes is not the result of Ohm's Law, rather Ohm's Law is the result of the actual facts.

In Fig. 37 we have the hook-up of a circuit that may have been upon the breakfast table this morning.

The generator furnishes a pressure which delivers a voltage, which means difference of pressure, in the lamp socket of 110 volts. The attachment plug leads this voltage to the toaster. The resistance of it I calcu-

lated by Ohm's Law, for it bears a label saying that it takes a current of 5 amperes.

This means of course that on an ordinary house lighting system it takes about 5 amperes. Ohm's Law

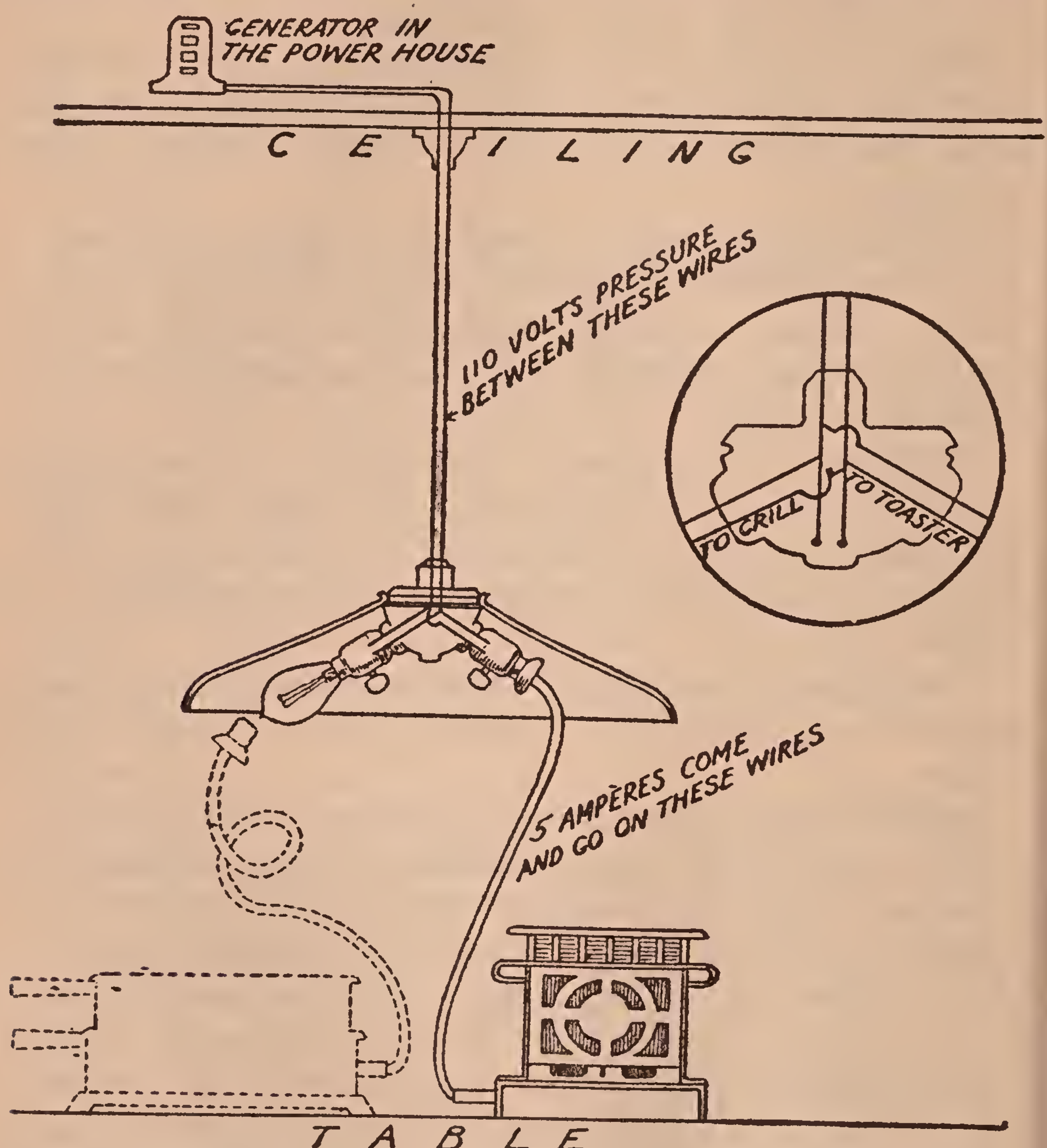

FIG. 37. DIVIDED CIRCUITS.

enables me to calculate that its resistance is about 22 ohms. See Problem II on page 150.

The generator and the toaster form a simple series circuit. Every lamp socket and every socket for an attachment plug in the house is connected to the same

wires. If then you now attach a grill to another lamp socket, and this grill has 22 ohms resistance, it will take 5 amperes also. This grill and its wires are shown in dotted lines in Fig. 37. You now know that connecting a second resistance of the same value as the first, in parallel with the first, doubles the value of the current taken from the generator.

Let us consider these two appliances as a unit. Perhaps wiring them in a different way would make this clear. Suppose we brought, as shown in Fig. 38, one wire from the attachment plug, split this wire so as to carry current to each appliance; then brought the two outlet wires back into one, and took this wire back to the attachment plug.

You would now have the same electrical condition as you had in Fig. 37 when the toaster and the grill were both connected to the chandelier. You have two 22 ohm resistances in parallel, and the resistance of the combination is half that of one resistance.

The effect is as if both the 22 ohm resistances were removed and one 11 ohm resistance were substituted. If you actually made that substitution a current of 10 amperes would flow.

This is a case where two equal resistances are in parallel. If the resistances of the appliances were unequal, calculating the result would not have been so simple a matter.

An actual experiment made with a 6 ohm and a 3 ohm coil in parallel would show that they will allow a current of such a size to pass as indicates that the combination offers but 2 ohms resistance.

COMBINED RESISTANCE.—You need rules for finding the actual resistance offered by a combination of several resistances in parallel, or as we say, their *combined resistance.*

There are two rules which will solve the problems arising from your experimental work.

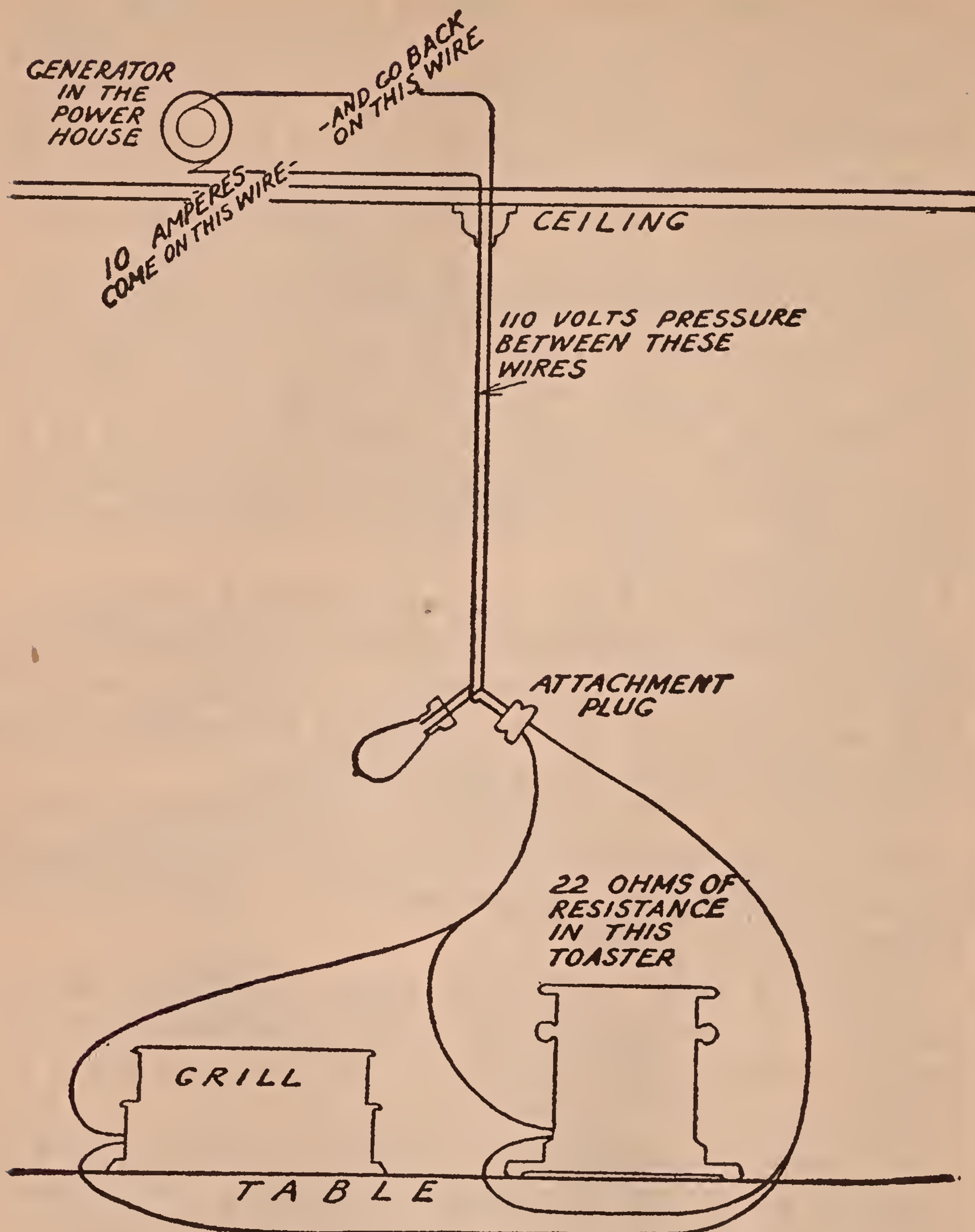

Fig. 38. Resistances in Parallel.

Rules for Computations.—1. The effect of placing a number of equal resistances in parallel is to add to the circuit a resistance equal to the resistance of one of them divided by the number of them.

2. The effect of two resistances in parallel is to add

to the circuit a resistance equal to the product of their resistances divided by the sum of their resistances.

Problem I.—Five lamps each of 330 ohms resistance are in parallel on a 110 volt circuit. What resistance do they offer to the passage of electrons?

Since they are all equal, their combined resistance will be $\frac{1}{5}$ of 330 ohms, which is 66 ohms.

Problem II.—Two resistances of 9 and 3 ohms each are connected in parallel. What is their combined resistance?

They are unequal, hence the "product divided by the sum" rule applies. $9 \times 3 = 27$. $9 + 3 = 12$. $27 \div 12 = 2.25$ ohms. The combined resistance will be 2.25 ohms.

An Old Error.—How often have I been told that the current followed the path of least resistance, thus leading me to infer that no current would go through a high resistance path when it was paralleled or shunted by a low resistance.

The truth of the matter came to me when I tried to induce current to leave a certain wire by placing low resistance shunts on that part of the circuit. Some current always flowed through the original wire.

The current divides and goes through all the paths offered to it, each path carrying a current in proportion to its conductivity.

Currents in Divided Circuits.—Suppose you have a small lamp, a resistance coil and a magnet, each of such a resistance that they will operate satisfactorily on a 2 volt supply.

Suppose you wish to connect them so that any one of the three can be operated alone or two or all three may be in use at once.

Experiment 25.—Take the device shown in Fig. 5 and fasten three wires to each terminal of the switch. Using one pair of these wires, connect a small S. P. S.

T. (single pole, single throw) switch and the lamp in series. Using another pair of wires, hook up a S. P. S. T. switch and the resistance coil in series. Use the third pair of wires in same manner for the magnet.

This hook-up is shown in Fig. 39. After the D. P. S. T. switch is closed, by operating the S. P. S. T. switches, any one device may be put in use or any combination made that you desire.

Close all the switches. A current flows and you would like to know how it splits. Notice that the 2 volts pressure is applied to each circuit just as if the

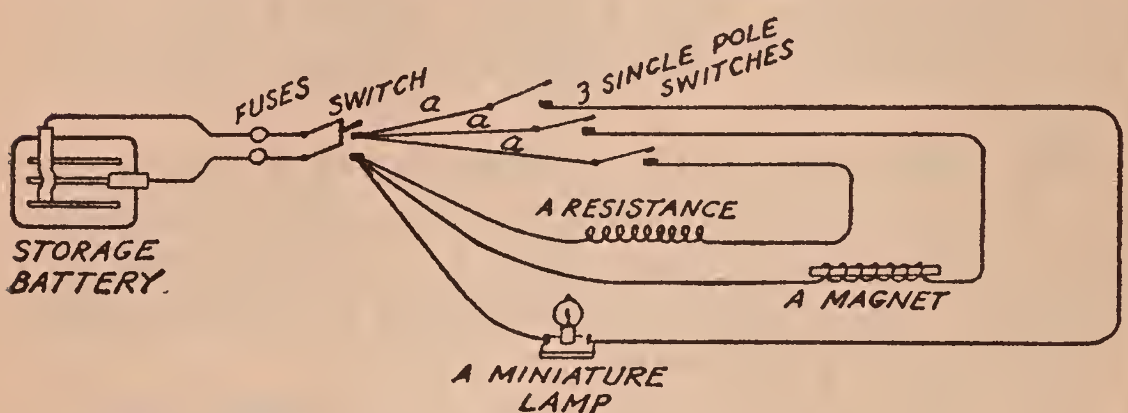

Fig. 39. Parallel Circuits.

others were not there. Convince yourself of this by opening first one and then another of the S.P. switches.

These circuits are all independent and each has a current in it equal to its resistance divided into the voltage of the cell. The current flowing from the cell will be equal to the sum of the currents in the branch circuits.

If you have an ammeter you may test this by inserting the ammeter in the places marked *a* and then in the wire from the cell.

Joules Law.—The toaster and all such heaters are devices containing wires whose resistance is so great that the electrons in pushing through create a friction that causes heat.

Every heating appliance that you purchase should

have a label on it, telling how many watts of power it uses up. Multiply by the number of seconds you have used the appliance, then divide by four. This gives you the calories of heat produced. The calorie is the unit of heat used by scientists. Engineers are more apt to use the B. T. U. for their heat unit. This B. T. U. is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

I Square R.—When an engineer uses this phrase he is talking about I^2R. If you multiply the square of the current in amperes by the resistance of the circuit in ohms you find out how many watts disappear in heat.

Problem.—A toaster on a 110 volt circuit takes a current of 5 amperes. Its resistance is 22 ohms. How many watts does it use? How many watts are turned into heat?

$$\begin{aligned} \text{1.—Watts} &= \text{amperes} \times \text{volts} \\ &= 5 \times 110 \\ &= 550 \text{ watts} \\ \text{2.—Watts} &= (\text{amperes})^2 \times \text{ohm} \\ &= (5 \times 5) \times 22 \\ &= 25 \times 22 \\ &= 550 \text{ watts} \end{aligned}$$

It uses up 550 watts and turns them into heat.

Why Big Wires.—When you think of the
i square r
loss you realize that the larger the wires carrying current to a place the less power is turned into heat and thus lost.

But, and this is a great big *but,* since to find the power lost in heat while the power is being brought to a place we square the amperes, before multiplying by the ohms, it is the current that counts the most. The size of the current is the vital factor in the I^2R loss, which is power lost in heat.

Why High Voltage.—There are many combinations of amperes and volts which will bring one kilowatt of power to you. Let us figure out a few. One kilowatt equals 1000 watts. Hence 1000 amperes at 1 volt pressure, 100 amperes at 10 volts, 10 amperes at 100 volts, 1 ampere at 1000 volts, all will deliver 1000 watts of power. Well, what is the difference?

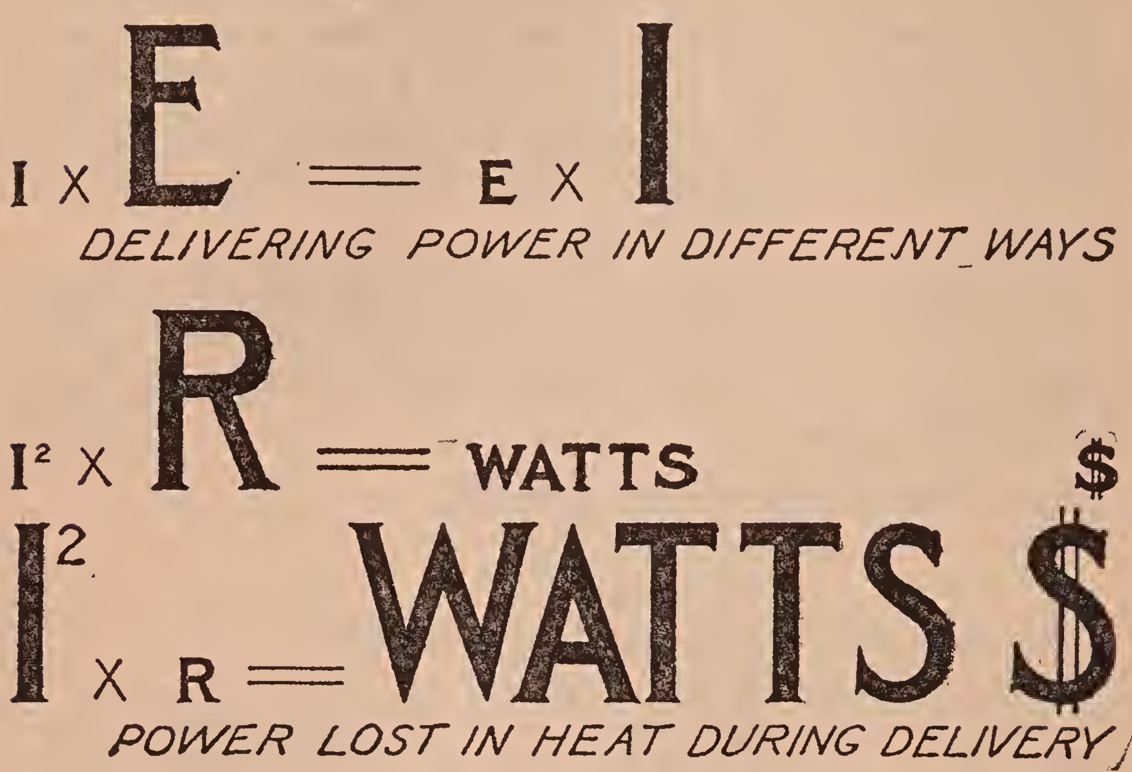

Fig. 40. Losses in Transmission.

As far as the consumer is concerned, there is no difference except in the price charged. But a watt is a watt, you will say. Why the difference in price?

Seeing things expressed in diagrams or charts helps the mind to grasp them. Look at Fig. 40. The iE and eI express the idea that power may be delivered in different ways. You also see that a small current may be delivered through a high resistance with a small expense for the watts lost in heat. A large current, although delivered through a small resistance, causes a large and expensive loss in watts.

The worst is however yet to come. A low resistance means large wires and these copper wires are expensive.

So the proper way to deliver watts will be by means of a high voltage and a low current through a moderate resistance. In this way the loss is kept down and the expense for copper wire made reasonable.

Drop.—Do not think that all our troubles in the transmission of electricity are solved. We still have an unavoidable drop to contend with.

To push electrons through resistance requires pressure, and a definite amount of that pressure is used up in the process. You cannot avoid this loss.

We call this loss *drop*. It is an old term that came into use because engineers pictured the current as dropping its pressure as it passed through resistance. So they said that there was a *drop* in the voltage.

The drop is calculated by the formula:

Drop = amperes $\times$ ohms, or expressed in letters:

$$V = ir$$

Modern engineers frequently refer to drop as the "eye-are loss." This, as you see, refers to the method of calculating it.

When one end of a long transmission line is kept at 30,000 volts, at the other end the pressure will be about 29,000 volts. The drop or *ir* loss being about 3 per cent of the e. m. f.

The electric company may keep the end of the circuit at their power station at 125 volts, but the unavoidable drop on the line will result in a pressure of about 120 volts at your home.

Warning.—Do not mix up the i^2r loss, which is a loss of power which wastefully heats the wires, and the *ir* loss which is a loss in the pressure.

Behavior of A. C.—Alternating current just naturally dislikes coils of wire. When d. c. goes

through a coil it makes a magnet and after that there is no more fuss. It is true that the current takes perhaps a second to get the magnetism built up, but after that second or fraction of a second the current which flows can be calculated by Ohm's Law.

When the electrons of a. c. start through a wire they build up the magnetism, but when they stop, just before they reverse their direction, the magnetism dies away. Then the electrons move back and build up the opposite kind of magnetism. This building up, dying down, rebuilding of magnetism in cycles uses up a lot of energy. This results in a smaller current of a. c. in a circuit containing coils, than the d. c. current would be.

It appears, then, that with an a. c. voltage sending current through coils you can not calculate the amperes by Ohm's Law. A circuit offers more resistance to a. c. than to d. c. This extra resistance to a. c. we call *reactance,* and the sum of the resistance and the reactance we call *impedance.* The actual calculation of these new factors we will leave for more technical books.

The Three Wire Circuit.—I have left this until the end of the chapter because I wanted you to have the contents of this chapter in your heads while building this model, which will let you see the arrangement of the wires in this method of delivering power.

Experiment 26.—A Model Electric Lighting Circuit.—You will need two dry cells, a porcelain three-wire, main-line plug cut out, three plug fuses for this, four 1.5 volt flash light lamps, and four sockets for them. The few feet of wire required you probably have on hand. If you can only purchase 3 volt lamps, buy four dry cells and use two wherever I say one.

A Two-Wire Circuit.—Arrange the cell, the fuses in their plug cut-out as shown in Fig. 41. Use only two of the three fuses in the cut-out. Attach the three branches to the main lines by soldering. In these

branches connect the lamp sockets or receptacles. Notice that in one branch there are two lamp sockets in series.

When you feel that you have gotten everything correct and shipshape mount this model on a board.

The reason for using such a big clumsy cut-out is to remind you that this or its equivalent is in your home at the place where the service wires first pass through its walls. Also, being a standard device, it can be purchased everywhere. Further, it is about the cheapest

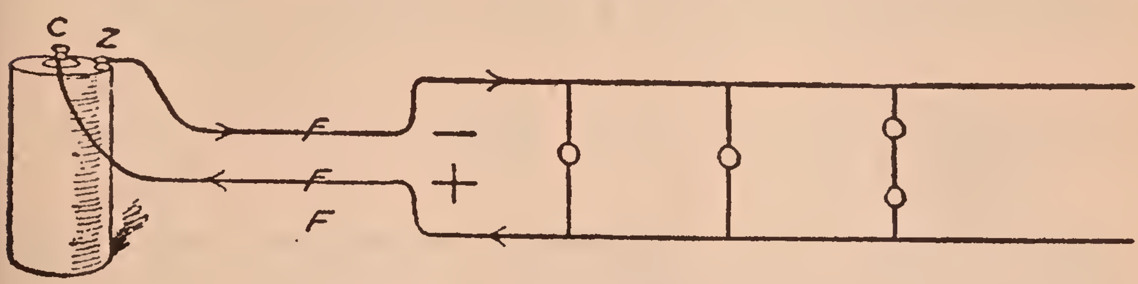

Fig. 41. Two Wire Circuit.

fuse holder that can be bought. We are planning to use the fuses as switches.

Take out the two fuses and you will see that the lines beyond them are dead. For this reason when repairs are to be made to the house wiring one should remove the fuses from the cut-out that controls the circuit.

Replace one fuse and notice that one side of the circuit is now alive. If a wire fell on your model so as to bridge across the gap, caused by the absence of the second fuse, then a current could flow. A circuit is never dead unless both fuses are removed.

Place both fuses in the cut-out and the lamps in the branches which have single sockets. Notice that they operate independently. These lamps are in parallel on the main circuit.

Now place two lamps in the branch that has the two sockets in series. Note that the lamps burn very dimly, for each lamp is under half its normal pressure. Notice that when one lamp is turned out, the other is also

extinguished. These lamps are in series and so act as a unit.

When you have learned all you can by turning lamps on and off, you are ready for "stunts." Be sure that you are using a dry cell or cells as your source of power before you do this part of the experiment.

Take a piece of bare (not insulated) wire about a foot long and lay it across the wires in every place and way that you can think of. Keep it on the wires just long enough to see clearly what happens, then take it

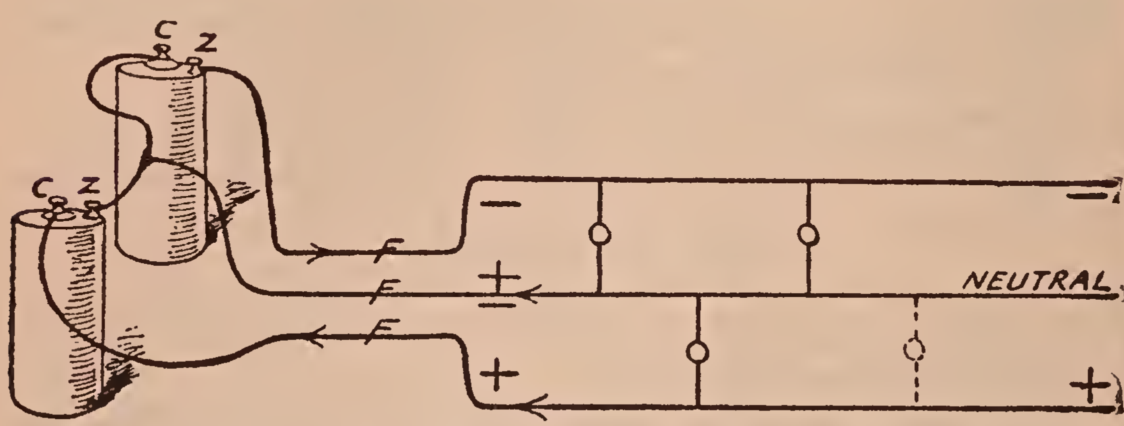

Fig. 42. Three Wire Circuit.

off and think out the explanation. Leaving these short circuits and crosses on the lines too long will wear out the cell.

Be sure to try the effect of using the wire as a shunt around one of the two lamps that are in series. Notice how the other lamp increases in brilliancy.

A Three-Wire Circuit.—*Experiment 27.*—Following the hook-up given in Fig. 42 you will have no difficulty in setting up this model of a three-wire system. Two things are to be noted. At first do not connect the branch shown in dotted lines. Do not attach the feeder to the neutral wire exactly as shown in the diagram. For clearness I have shown this feeder attached midway between the cells. This makes it clear that the

neutral or middle wire is positive to the upper line but negative to the lower line. For that reason it is marked both + and —.

From the diagram you can see that the neutral feeder is under the influence of a zinc and a copper electrode at the same time. Thus it is proper to call it neutral.

In the actual set-up the neutral feeder could be attached to the nearby zinc electrode or to the nearby copper electrode. The electrical result would be the same as that obtained by connecting exactly as shown in the hook-up.

Insert the three lamps. Consider the flow of the electrons, which is opposite to the direction of the flow of current.

The electrons for the two lamps flow down the negative wire and passing through the lamps, find two paths open to them. The path through one lamp will only carry half of the electrons, so they split. Half go back by the lamp and half by the neutral wire.

The lamps and appliances of any house or factory are so distributed over the two parts of a three-wire system, that of those devices apt to be used at the same time, half are on each part of the system. The electrician says "Half on each side."

Suppose the division to be skillfully made. The neutral wire carries a flow of electrons just equal to the amount of lack of balance of the load.

Now connect in the branch shown in dotted lines and insert a lamp in it. Now all the electrons coming down the negative wire may pass through and go back on the positive wire.

To prove that they are doing this, you may take out the fuse in the neutral wire. This cuts off the neutral feeder, yet the system is not affected. The neutral wire is there to carry electrons for the unbalanced load. Hence the neutral wire can be one half the size of the other two.

The saving in money that would be spent on copper is very large. In the larger cities where hundreds of thousands of dollars' worth of copper is in the service mains, this saving is very important.

You must now experiment a little, turning off lamps here and there, making all the short circuits you can,

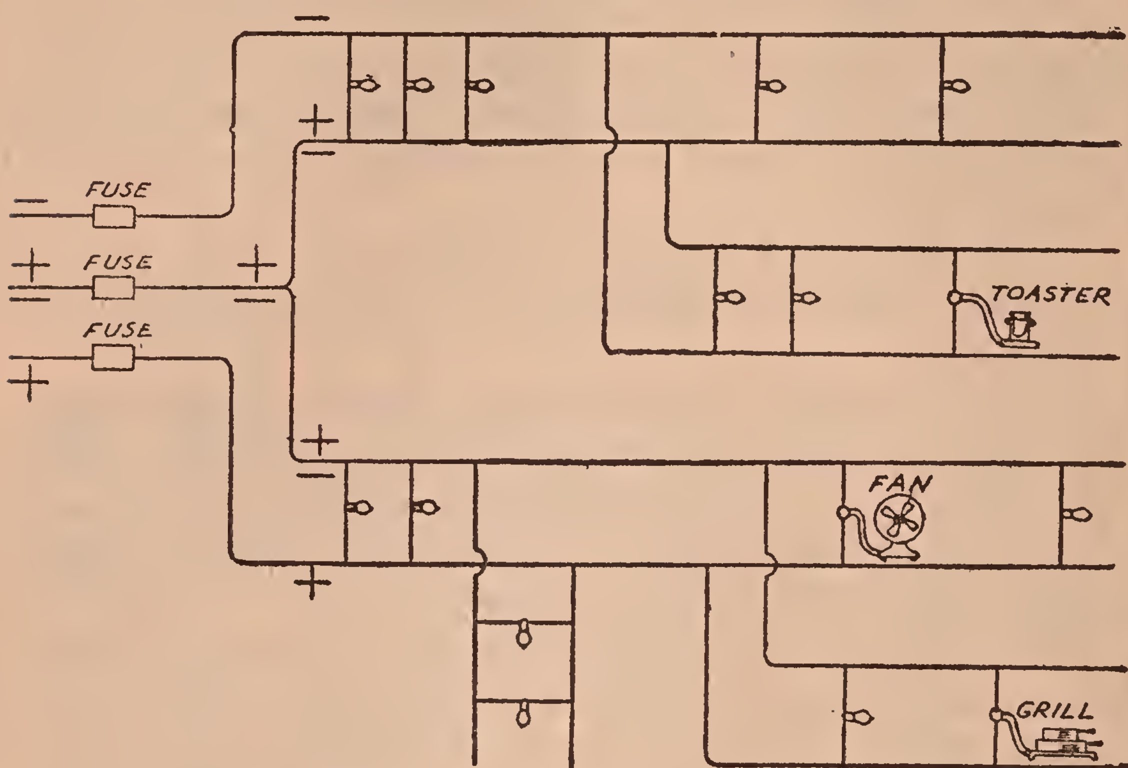

FIG. 43. THE HOUSE WIRING.

making crosses between the wires at different places, until you *know* a three-wire circuit.

Be sure to try the effect of an unbalanced load when the neutral fuse is out.

In many places there is no fuse in the neutral wire and it is grounded. This prevents 220 volts being accidentally put on the 110 volt devices on one side of a three-wire system.

IN YOUR HOUSE.—If a three-wire service enters your home you will not find three wires running to the lamps and appliances throughout the house.

The neutral will be split and it, with one of the out-

side wires, meaning the positive or the negative wire, will be carried as a pair through the house.

Thus two two-wire circuits in the house, whose probable loads seem to be equal, will be attached to a three-wire supply as shown in Fig. 43.

110 Volt Control Panel.—*Experiment* 28.—Your study of the model circuits that you have built out of the house wiring system should have taught you to avoid certain things.

You ought now to be able to build and operate a device for connecting 110 volt lines to your experiments. Remember that your friends will want to see your work in operation. They will want to see just what you do. "Please let me try it" will be a frequent request. So you must have things neat, shipshape and fool-proof.

First we want a *hook-up* as shown in Fig. 44. Then we want a full size *lay-out,* which you will make on heavy paper. Finally we will mount the apparatus on a base board, using the lay-out as a guide.

When you start to build something from a hook-up diagram, you should proceed in a regular and orderly manner.

Always make a copy of the hook-up on a sheet of paper large enough to make notes on. Check your copy with the diagram in the book, wire for wire, seeing that you know clearly what apparatus is meant by the different symbols.

The hook-up in Fig. 44 shows an attachment plug at A connected to a porcelain two-wire main-line plug cut-out. One of the wires from this leads to a porcelain moulding receptacle and from this to another one of them. These are shown at B. With these come caps, shown at C. These caps are to be wired. To the wires at R and M may be attached resistances or an ammeter.

Should you not wish to use these wires for inserting

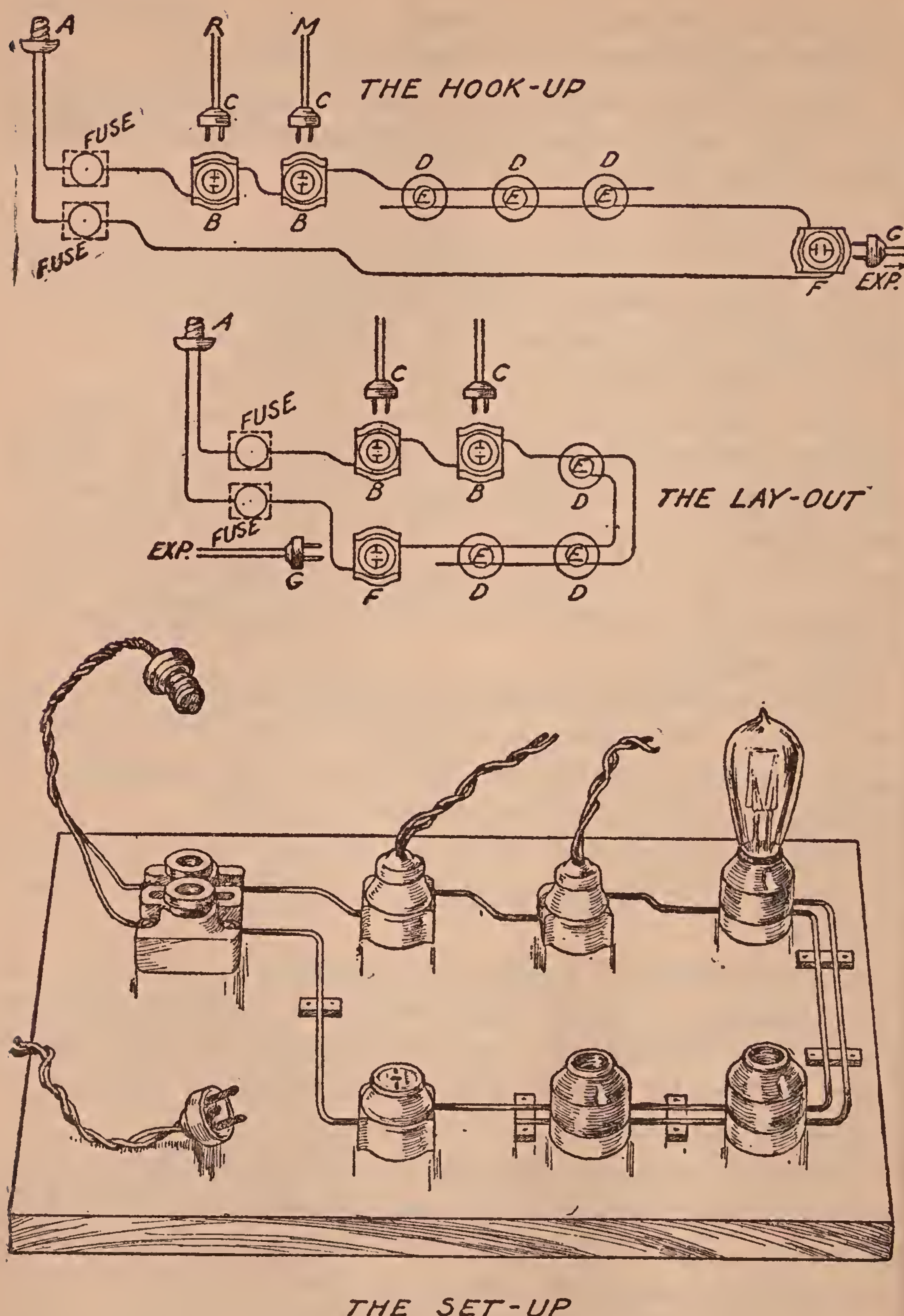

FIG. 44. 110 VOLT CONTROL PANEL.

resistances or meters into the circuit, you may twist these wires together to complete the circuit. This will not cause a short circuit because there are lamps in the circuit.

The wire from the second receptacle is attached to one side of three porcelain moulding lamp receptacles. These have lamp sockets in them at E. To the other side of these a wire is attached which goes to a receptacle F, exactly like the one at B. From the other side of F a wire leads back to the cut-out. The experiment is connected to the cap G.

The Lay-Out.—This device could be laid out on a long narrow board, but it will be much more convenient to handle and stow away when not in use if its dimensions are changed.

To make the lay-out which I have indicated, start with a sheet of heavy paper or thin cardboard. Assemble the apparatus on this in the arrangement of the lay-out. Draw the wires as pencil lines and then carefully compare the lay-out with the hook-up, to see if they are the same electrically.

When all is arranged, run your pencil around the different pieces to mark their positions. Remove the apparatus. Trim the paper to a convenient size and hunt up a board for the set-up.

The Set-Up.—Upon the board that you have selected as a base lay the paper lay-out, and with a nail punch holes through in enough places to accurately mark the places for the different pieces.

Now screw down the seven pieces of porcelain, wire them up with rubber-insulated wire and insert the two fuses. The three caps and the attachment plugs are to be wired, and then we are finished. In wiring the caps and attachment plugs take great care that the bare ends of the wires near the attaching screws are not near each other. Only remove the insulation at the spot that is going under the screw head.

Its Operation.—Insert 2 ampere fuses in the cut-out. In the lamp sockets at E place 110 volt incandescent lamps. The greater the number of watts mentioned on the label of the lamp, the greater will be the current that the lamp will allow to pass. Divide the watts on the lamp label by 100 and you will have the amperes that the lamp will pass. To be exact you should divide by the actual voltage in your home.

The lamp receptacles D are in parallel, hence the current passed by each lamp adds its value to that passed by the others. Current will flow if one lamp is inserted. After that more lamps or lamps of higher wattage will increase the current.

The wires from any of the caps C or F may be connected together without causing a short circuit. Be very careful of the wires up to the cut-out, for your fuses do not protect these wires.

This device will operate on a. c. or d. c. and with any lamps from the 104 volt lamps up to 220 volt ones. The latter are seldom on sale. Should you use this at a summer home with a private lighting plant, the voltage will probably be about 30, and so you should use the lamps that are sold for such systems. A 110 volt lamp on a 30 volt circuit will only allow about ⅓ of the current to pass that it would on its proper circuit.

Polarity Indicator.—If you have a d. c. supply you may charge a storage battery by using the 110 volt control panel. Do not connect the battery to G yet. Take the wires from G and touch to a polarity indicator and then when you have found which is the positive wire connect it to the positive pole of the battery.

Making a Polarity Indicator.—*Experiment* 29.—If you can find a tube with a ¼ inch or larger bore (hole inside) you will avoid much trouble. If you can not find one you must make one from a small test tube.

One three inches long is most convenient, but the length is not of real importance. Soften the bottom of the tube by heating it red hot. A wire held by pliers so that but 1/4 inch projects can be thrust through the softened glass. Keep the glass in or near a small flame to cool it slowly. The wire will be welded into the glass.

Thrust a wire through a cork that will fit the other

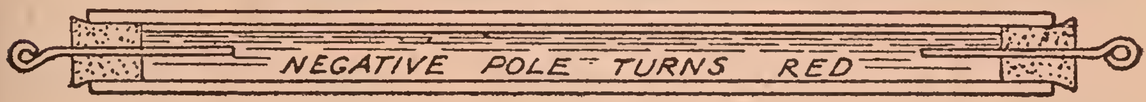

Fig. 45. A Polarity Indicator.

end of the tube. If you found a tube with openings at each end you should fit corks in these.

Make a solution of salt so strong that some salt remains in the bottom of the glass undissolved. Dissolve one gram or 6.5 grains of phenolphthalein powder in a teaspoonful of medicated alcohol. Add half of this solution to enough salt solution to nearly fill your tube. The solution should be colorless. If it is pink, then the salt was not absolutely pure or your glassware not clean. In this case mix ten drops of vinegar in a third of a glass of water and add a drop at a time to the salt solution until it is colorless.

Fill the tube nearly full, insert the cork and you are ready for a test.

Touch the wires from a cell, or some d. c. supply, and the end which turns pink is the negative wire. Shake up the solution and the color will disappear.

Don'ts for 110 Volt Circuits.—1. Do not turn on the current until you are sure that the experiment is set up exactly like the hook-up; and that all loose wires and tools have been put away.

2. Do not use "any old fuse." Use those with the smallest current capacity possible. Better blow a fuse than blow your apparatus.

3. Do not open and close circuits at the key or chain of the socket, nor at the attachment plug. Use a switch in the circuit or the cap G of your panel.

4. Do not leave your experiment connected to the house supply when you leave the lab, although it is just for a moment. At least pull out the cap G, and better yet, also take out the attachment plug A.

5. Do not work in a hurry. Many a dinner has been eaten by candle light because just as "Dinner is served" floated up stairs, the son hurriedly connected a rush job to the house system. Instead of working, it blew.

CHAPTER VIII

HOW ELECTRICITY COMES TO US

Conductors
Leaders
The Wires in a House
The Underwriters' Rules
Materials for Conductors
    Comparison of Conductivity
        Experiment 30
Measurement of Resistance
    Resistance by Substitution
        Experiment 31
    Resistance of a Galvanometer
        Experiment 32
Relative Resistances
    Wire Tables
        Table A
        Table B
    Use of a Wire Table
Effect of Temperature on Resistance
    Experiment 33
The Underwriters
Uses of Resistance
Two Ways of Explaining
Our Old Friend I^2R
Laws of Resistance
How a Wire Conducts Electricity
Insulators

CHAPTER VIII

HOW ELECTRICITY COMES TO US

Conductors.—The wire that brings the electrons to us is called an electrical conductor, but this is not a perfect name for the things that persuade the electricity to go in a particular path. The word *conductor* reminds me too much of a conduit, which is a hollow affair. Now, electricity does go through a wire, but also on and around the wire.

Leaders.—When a boy, I watched the plumber put new pipes down the outside of the house, to carry the rain water down from the roof. He called them "conductors," but I called them "leaders." He used his name because they conducted the water, and I used my word because they led the water. Well, we were both right.

I have often thought of a situation in which my name of "leader" would be the better name. Suppose a new kind of rain began to fall. The burning question, if I may use such a word in reference to very wet water, would be, "How will this new kind of rain act?" On rushing out to see, every one would be amazed at this new rain. It would come sliding down the roof, turn suddenly at the edge and flow along the *outside* of the gutters to the leaders and then down the outside of the leaders to the ground. Yet it would cling close to them as if by magic. Then truly the leaders would be leaders and not conductors.

For high frequency alternating currents the wires act more like leaders, while for low frequency a. c. and for d. c. they act like conductors. Since the current always uses some of the wire to travel upon, we use the same material to persuade all kinds of current to come to the place where we want the electrons, and this material is copper.

We are always trying to persuade electrons to come to us from the place of high pressure, do some work, and go back home. Rather, since an electron has no real home, we want it to go back to where it obtained its force and get a new supply of push and pep. We must try to make the trip an easy one. To do this we use copper.

The Wires in a House.—Investigation of the wires around a home show that two conductors usually are bound together by a covering to protect them from wear by friction or by bending. Inside the walls or on the cellar ceiling you may find this cable or cord of two conductors drawn into a system of iron pipes to protect them from hammer blows, or nails driven during repairs to the building.

Sometimes the cord is covered with a flexible interlocking metal armor. This is called BX by the electrician.

The two wires inside of the outer protection are each covered with rubber and cotton. Often the copper conductors are each composed of many fine wires twisted together. This makes the conductor flexible. The wires in the walls are solid copper.

All movable appliances such as irons, toasters, grills, heaters, floor lamps, vacuum cleaners and such devices have an extra cotton covering on the flexible cord. This in turn may be covered with silk to improve its appearance.

But why all this fuss? Why the rubber and the cotton, why the careful protection?

The Underwriters' Rules.—A group of men have made a set of rules to protect ignorant folks, so that they won't lose electricity by leaks nor get too many electrons in one place at one time. Either of these things may create enough heat to start a fire.

The fire insurance people, or the underwriters, as they are called, have by experience learned how wires should be protected. We must have the wire guarded from wear and tear, from mechanical injury due to accidental blows, and there must be a rubber covering to prevent the electrons from leaking off the wire. The underwriters maintain a laboratory where all new electrical devices are tested for their mechanical protection of the wires and for the character of the insulation on the wires.

No device should be used in a building upon which fire insurance is carried unless it has been approved by this laboratory. No wiring nor additions to the wiring of such a building should be used until the proper officers have inspected this wiring and issued a certificate.

Should a fire occur and you have no certificate the insurance company may properly refuse to pay any insurance until it has been proved that no wiring or electrical appliance was the cause of the fire.

Experience has taught us that for portable apparatus solid wires are stiff and clumsy. They would soon break by the constant bending and kinking to which they are subjected. For that reason all portable appliances are connected by stranded wires.

A few paragraphs ago I was mentioning insulation. We are not quite ready to discuss it. The voltage of my brain made the current of my thoughts run ahead too fast. I will throw a few ohms in my mental circuit and slow up, to turn back to the discussion of conductors.

Materials for Conductors.—Silver and copper conduct electricity and lead it with about the same ease. Just as every crowd offers some opposition or resistance to folks walking through it, just as the air offers resistance to the passage of an airplane, so does every material offer resistance to the passage of electrons.

Comparison of Conductivity.—We use the *ohm* as a unit of resistance to compare the conductivities of materials. The *ohm* has been defined in Chapter VII but there are several ways of forming a resistance of one ohm in a practically accurate way.

Two pounds of bare (uninsulated) No. 16 copper wire, 250 feet of No. 16 copper wire, 62 feet of No. 22 copper wire, 9 feet 7 inches of No. 30 copper wire. Any one of these pieces of wire has about one ohm of resistance, near enough for you to use these as units of measurement.

Experiment 30.—Using No. 30 cotton-covered wire, wind on empty spools a series of resistances. If you will make one 1 ohm, two 2 ohms, one 6 ohms and one 12 ohms, you will be able to obtain all the combinations from 1 to 23 ohms. Two feet four inches make one ohm when No. 30 copper wire is used.

You will need a connection board so that any combination of these resistances can be quickly made. Select a piece of smooth wood about eight inches long and one or two inches wide. Drill or burn holes half way through the wood at equal distances apart, say about one inch. Fill these holes with mercury.

The use of this connection board is apparent in Fig. 46. Placing the ends of a coil in the holes places it in the circuit. The jumpers should be made of heavy wire or, as shown, of ordinary wire bent so that four wires carry the current. All ends should be sandpapered bright and clean before insertion in the mercury.

Set up a series circuit with a few cells, the connection board, and the galvanoscope with the shunt coil B attached to it, like Fig. 47.

Vary the resistance of the circuit by inserting in succession the coils you have just made.

By the change in the galvanoscope reading you can tell which coils are high and which are low in resistance. Selecting any two coils, by placing first one and then the other in the circuit, you can tell which is the higher

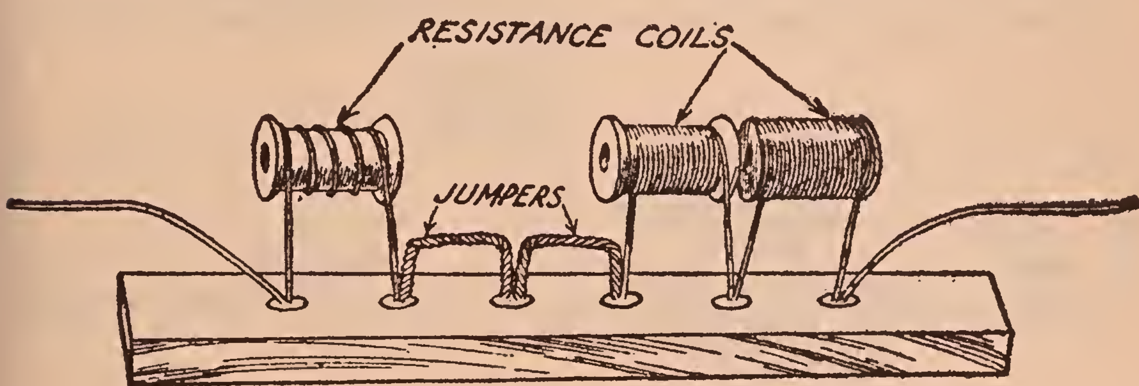

FIG. 46. A CONNECTION BOARD.

resistance. But since the coils are not the only resistance in the circuit the changes in the current as shown by the galvanoscope are not proportional to the resistances of the coils.

Measurement of Resistance.—The method of substituting known resistances for the unknown until the current is brought to its previous value makes use of the principle called Ohm's Law.

If the voltage is the same and the current is the same then the two different resistances used are equal.

RESISTANCE BY SUBSTITUTION.—*Experiment* 31.—Select some coil whose resistance you do not know. Set up the experiment from the hook-up given in Fig. 47. The switch, or push button, could be omitted and the current broken by using a jumper. If the deflec-

tion of galvanoscope is too small when the unknown coil is in the circuit then use two cells.

Remove the unknown coil from the circuit but leave everything else exactly as it is. Substitute for the unknown coil such a combination of your resistance coils as will make the galvanoscope give the same deflection. The resistances you have put in are equal to the unknown resistance that was in the circuit before.

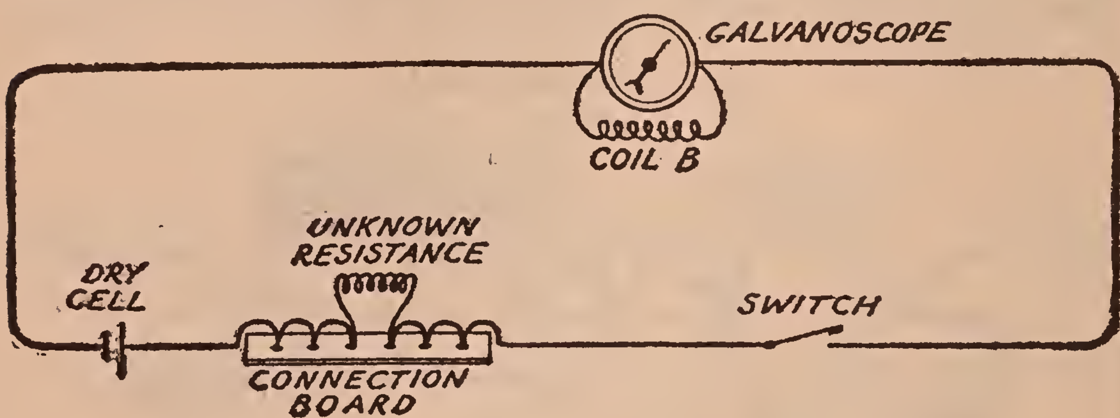

Fig. 47. Hook-up for Measuring Resistance.

The reason is, that with equal voltages the same current is passed by equal resistances.

Resistance of a Galvanometer.—*Experiment* 32.—You may have only one galvanometer and wish to know its resistance. Here is a method for finding the resistance of a galvanometer while using it to give the readings needed.

The method is called *The Half Deflection Method.* Connect the galvanometer in series with a cell and the connection board. Add enough resistance to give a deflection of about half way up the scale. Our galvanometer reads from 0 to 8. Adjust the added resistance until the deflection is about 4. Call this resistance R.

Do not disturb any of the circuit except to remove jumpers and insert more resistance into the circuit until the galvanometer reads half the previous deflection.

The total resistance now connected to the circuit by means of the connection board we will call r.

The resistance of the galvanometer will be r—2R.

For an example. With 5 ohms inserted at the connection board the reading of the galvanometer was 4. With 7 ohms added, or a total of 12 ohms, the deflection was reduced to 2. The resistance of the galvanometer was $12 - (2 \times 5)$, which is $12 - 10 = 2$ ohms.

You might also find the combined resistance of the galvanometer with coil A in series and the combined resistance of the galvanometer with coil B in parallel.

Relative Resistances.—The resistance of a piece of silver wire might be 98 ohms. Then the resistance of a copper wire of exactly the same size and shape would be 108 ohms. You see that it would not pay to spend a lot of money for this small increase in conductivity.

If the wire we were talking about had been of aluminum its resistance would have been 172 ohms. This would seem to kill the idea that aluminum might be used in place of copper. But for the same conductivity the aluminum wire, although larger, has only half the weight. When wires for the transmission of power are carried across the country on steel masts, such as are shown in the Frontispiece, weight counts. Such wires are often made of aluminum.

Wire Tables.—Engineers who are designing apparatus need a lot of information about wires. The diameter, the number of feet in one pound, the resistance of 100 feet, the number of feet in one ohm of resistance and the current that the wire will carry without too much heating, are all needed at one or another time in his work.

For such information he uses a wire table. You will not require a complete table, so I am giving you the information that will be of greatest service.

Table A.—This table is for bare, that is, not insulated copper wires. For experimental use, the carrying capacity of a wire is that current which will permit you to hold the wire in your hand. If you use a larger current, the heat may be stored up in poor conductors of heat, such as paper, which catches fire easily.

Resistance coils that you are planning to run at high temperatures should be insulated with asbestos and porcelain, then mounted on metal and slate.

Table B.—An alloy of nickel, copper and zinc, called German silver, makes a smaller coil for a given resistance. This alloy is named, in the stores, according to the percentage of nickel in it. Eighteen per cent wire has that per cent of nickel in it. Thirty per cent wire has higher resistance and higher cost.

Use of a Wire Table.—Suppose I wish to wind a 5 ohm coil and I have a spool of No. 30 copper wire. From the table I find that this wire has a length of 9.7 feet for every ohm of resistance. Multiplying by 5 gives 48.5 feet as the required length.

Suppose two telephone receivers have a resistance of 3000 ohms, which is 1500 ohms for each one. They are wound with No. 36 copper wire. How much wire on each one? A resistance of one ohm requires 2.4 feet, hence each receiver contains 2.4 × 1500, or 3600 feet. The two contain over a mile of wire.

Effect of Temperature on Resistance.—Some wires made of patented alloys do not change their resistance with the temperature. Expensive but very accurate measuring devices use coils of such wires.

Copper increases in resistance as it increases in temperature, but not enough for us to worry about unless we attempt to force large current through small wires.

Effect of Temperature on Resistance.—*Experiment* 33.—On a piece of asbestos wind a coil of 10 feet of No. 30 bare iron wire. Connect this in series

Table A—The Properties of Copper Wire

Size of wire	*Diameter in inches*	*Feet in* one pound*	*Resistance of 100 feet in ohms*	*Feet for one ohm*
14	0.064	80.4	0.25	396.6
18	0.040	203.4	0.63	157
20	0.032	323.4	1.01	98.7
22	0.025	514.2	1.61	62
30	0.010	3287	10.3	9.7
36	0.005	13210	41.4	2.4

* Note that this refers to a bare or uninsulated wire.

Table B—The Properties of German Silver Wire

Size	*Resistance of 100 feet in ohms*		*Feet for one ohm*	
	of wire called 18% *German Silver*	*of wire called* 30% *German Silver*	*of wire called* 18% *German Silver*	*of wire called* 30% *German Silver*
20	19	28.5	5.26	3.51
30	193	289	0.52	0.35

with the galvanoscope with its shunt coil B attached to it. Support the coil of iron wire above the bench by glass rods.

Connect as many cells as are needed to give a deflection of half the scale. Then with an alcohol lamp or Bunsen burner heat the wire hot. The indication of the meter will lessen, showing that a smaller current is flowing.

The Underwriters have set certain limits for rubber covered wires on 110 volt circuits, when the wires are enclosed in the walls or in mouldings. The limit for a No. 18 wire is 3 amperes. This size is called *fixture wire,* for it is used in wiring chandeliers, floor and table lamps. The No. 14 wire, which is the smallest size used in the walls or in BX, may carry 12 amperes.

The fire insurance people are afraid of the heated wire causing a fire. They do not want a heated wire to cook its rubber insulation to a brittle material, which would crack and lose its insulating properties.

Uses of Resistance.—Wires of nickel silver, German silver, bronze, chromel, Krupp alloy, bronze and steel are used either to choke off undesired volts and thus reduce the flow of electrons, or to offer such an opposition to the passage of the electrons that the wires will grow hot.

You may have a lamp in a child's bedroom or in a bathroom. This lamp you wish to use at a very low candle power and yet be able to turn on at full candle power instantly.

The double filament lamp solves the problem. But this requires a special lamp. There is a device made like a lamp socket which is a variable resistance. Pulling the string dims the light. Why? Because there has been put into the circuit enough ohms to use up and destroy part of the 110 volts pressure. The remaining

pressure cannot force enough electrons through the lamp to light it to normal brilliancy.

There is another way of explaining this. When you pull the string you add a resistance to the circuit which, with the resistance of the lamp, makes the total resistance too great for the normal current to flow. Less current, less heat, so the lamp gives less light.

Two Ways of Explaining.—This is a good place to tell you that quite frequently two persons may give different explanations of the same thing. That is, they explain the same thing from a different standpoint. They thus get the facts at a different "slant." When these two explanations are carefully gone over you will find that they are both correct. Probably one explanation will get into your head and stick there better than the other. It is for this reason that I advise you to talk over problems with all your friends and teachers. If doing this merely confuses you, then your elementary and fundamental knowledge is lacking in quantity or quality. Improve both by reading, experimenting and thinking.

You cannot get along without books, for you may have them with you at all times. But when the real live person who *knows* is around, leave the books and get him to talk.

Our Old Friend I^2R.—A power transmission engineer would not like me to call I^2R a friend, because when he transmits power from a waterfall to a city he does not care to heat the air between them. Yet he can't help doing some heating. There is the resistance of his transmission line, and its effect is to produce heat when the electrons pass through it.

You and I want toasters and electrical heaters, so we put a lot of resistance in a small place and count the heat produced as useful, not as a loss.

We do not want to heat the walls of the home, so

we use large wires of low resistance to bring the current to the place where we will use it.

Laws of Resistance.—1. The resistance of a conductor is the same for all values of current unless the current heats the conductor.

2. For copper wire, the higher the temperature the greater the resistance.

If resistance is 10 ohms at 70° Fahr., it will be 12 ohms at 125° Fahr., and 13 ohms at 180° Fahr.

3. For direct current and low frequency alternating current it is the area of the cross section of the wire which conducts.

Hence resistance diminishes as the square of the diameter of the wire. Twice the diameter, one fourth the resistance of previous wire.

4. For high frequency alternating current it is the surface also that leads the current. Hence stranded wires should be used.

5. The resistance increases with the length of the wire.

6. Every material has its own special resistance.

By cross-section we mean the area of the end of the wire when it has been cut across perpendicular to its length.

How a Wire Conducts Electricity.—A copper wire is composed of atoms, and these atoms of electrons and protons. Many of the electrons are held by the protons in the nuclei of the atoms, but the rest are quite a distance from the nuclei and free enough to wander from atom to atom.

When an e. m. f. is applied to the wire these free electrons are urged in one direction and it is this movement of electrons in the conductors that we call current.

Compare the wire to a sidewalk, as I have done in Fig. 48. The boys are the electrons. The sporting goods store, the candy shop, and other attractive show windows will represent the protons. The boys who

crowd up to those windows represent the electrons held firmly by the protons of each nucleus.

The boys coming towards us are urged onward by an e. m. f. behind them (school is out), and also by a pulling force before them (there is food at home).

FIG. 48. HOW A WIRE CONDUCTS ELECTRICITY.

But there are always some electrons moving in the wrong direction, which cause friction and some heated words.

Finally the onrush of electrons may be great enough to push some of the electrons off the wire into space, just as on our sidewalk the jostling and pushing has shoved two boys into the gutter.

I am sure if some one in the rear called "Fire" that in the commotion that would result, it would be harder for any one boy (electron) to walk through the surging, swaying crowd. Thus the wire offers extra resistance to alternating current.

Now if a fight, a good "scrap" started in the center of the crowd and it swayed back and forth, in an excited way, at a high rate, I am sure still more boys (electrons) would be shoved off into the gutter.

In the same way high frequency a. c. pushes many electrons of the wire into the adjacent space.

Insulators.—There are materials like glass, porcelain, rubber, gutta percha, bakelite, paraffin, oils, resins, shellac, slate, mica, sulphur, silk, wool, cotton, paper, and dry air which, while composed of protons and electrons, will not conduct a current of electricity.

Although subjected to the stress of high electronmotive forces, the electrons of these materials refuse to budge. As we have no flow of electrons, there is no transfer of electrical charges and no flow of current.

These materials are called *insulators*. They are used to keep electrical charges and currents where we want them, and out of places where we do not want them.

CHAPTER IX

MAGNETISM

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MAGNETISM

Lodestone.—As far back as 2800 years ago, the Greeks knew that this black stone, which is really an oxide of iron, attracted iron. Homer and Aristotle mention it. A Roman poet who lived before Christ was born tells how iron rings may be made to hang in a chain from a piece of lodestone.

Origin of the Names.—This black iron ore occurred in large quantities in the district of Magnesia. Thus the name of Magnesian stone was applied to it. Later in England the name of *magnet* was coined from the name of the country where it came from.

About the tenth century, it was discovered that a piece of this mineral when freely suspended, turned until it pointed in a north and south direction.

This peculiarity gave it the name of leadstone or *lodestone.*

Lodestone was used to magnetize pieces of iron and steel by stroking them. These artificial magnets were used by the Chinese as a compass, for sailing, about the year 1300.

To Make a Magnet.—*Experiment* 34A.—Lay a piece of hard steel, such as a small drill or part of a hack saw blade on the bench before you. Hold a bar of magnetized steel in a vertical position and stroke the drill from end to end as shown in Fig. 49.

If you use the N end of the magnet for stroking, the

part of the steel last touched at each stroke will be a south pole.

As magnets made by this process are not very strong, the practical use of magnets did not develop until the electro-magnet was discovered in 1825.

Experiment 34B.—Twist a copper wire around a test tube or pencil. The shape of your coil is a *helix*. Connect the ends of this helix to a battery and current

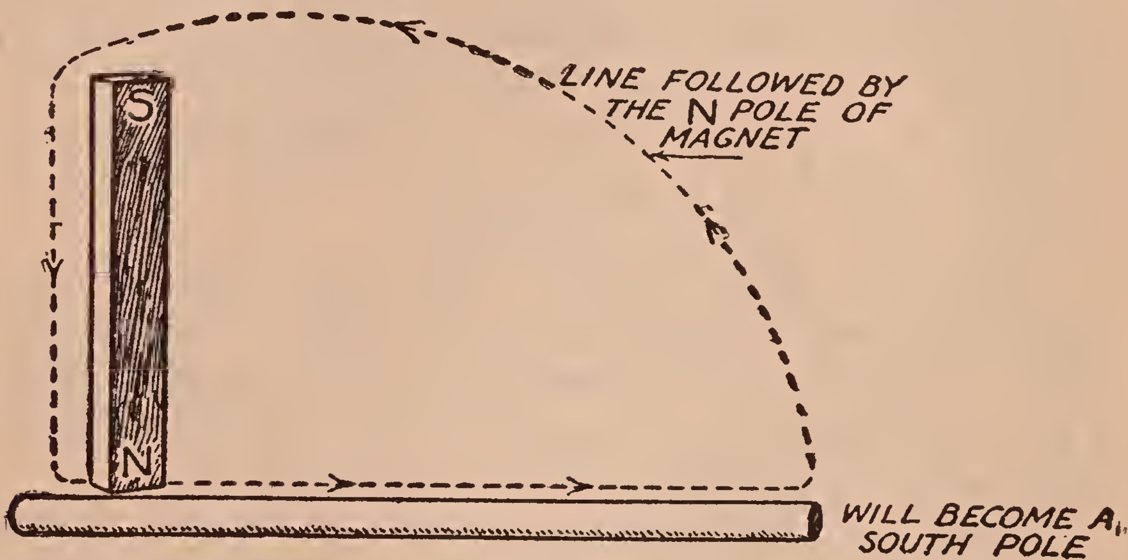

Fig. 49. Magnetizing Steel with a Magnet.

will flow, making it a weak magnet. This coil carrying a current we call a *solenoid*. See Fig. 50.

Place a piece of steel in this helix and pass a large current through it, thus making it a solenoid. Although the current did not pass through the steel it will become magnetized.

Practical Details.—Connect the nearer end to the carbon or + pole and the farther end to the zinc or — pole of the battery. One cell is shown, but five cells in series are needed to produce a strong magnet.

While the current is passing, hit the steel several sharp blows with a piece of wood.

Should your magnet be too weak although five cells

are used, then the steel you have is very hard and difficult to magnetize.

You will then connect the 110 volt control panel to a d. c. circuit, fill the lamp sockets with 50 or 80 watt lamps and then attach the helix.

Rule for Polarity of a Solenoid.—If the set-up of your experiment followed exactly the hook-up given

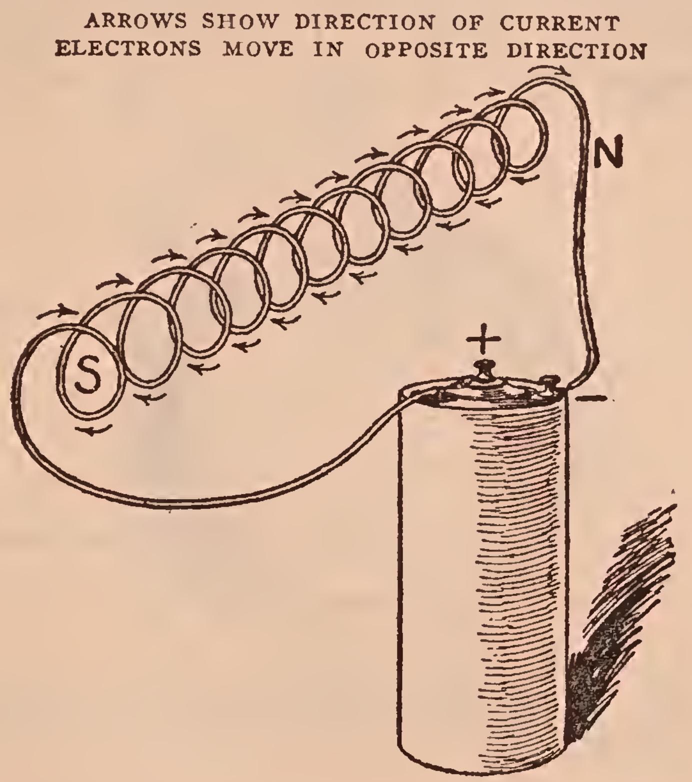

FIG. 50. MAGNETIZING STEEL WITH CURRENT.

in Fig. 50, then the nearer end of the solenoid will be a south pole and the magnets made in this solenoid will have the same polarity as the solenoid.

POLES.—The parts of a solenoid or magnet which attract or repel each other are the poles. The north pole is the part which points northward when the magnet is freely suspended.

The poles of a magnet are very near the ends of the material, but not, as you would suppose, exactly at the ends.

Poles only occur where the material changes from a magnetic substance to a non-magnetic one. This is

why there are no poles along the magnetized bar, but only near the ends.

If a helix is wound on a solid ring of iron and a current passed through the wire, no poles will be found. With a hack saw cut out a portion of this iron ring and remove it. Poles will develop on each side of the gap. Fig. 51 shows such a ring magnet.

Forces Between Poles.—Like named poles repel, unlike named poles attract. It is evident then that the pole of a magnetized bar which swings around to the

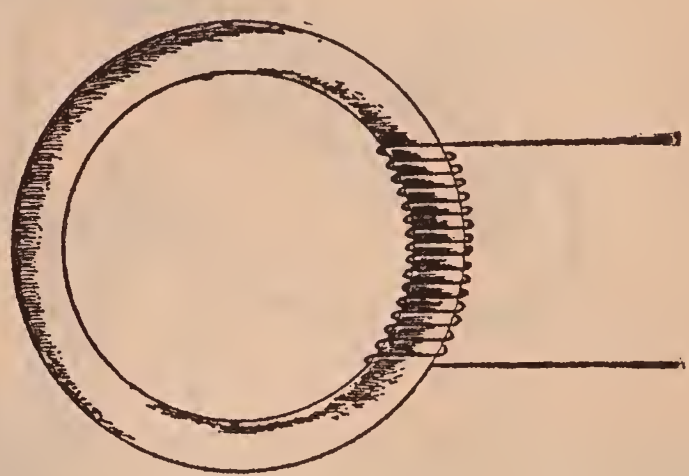

Fig. 51. A Ring Magnet Showing no Poles.

north is really of south polarity. But this end that swings northward has been called the north pole for so long that we keep the name although we recognize the error.

The French, more accurate than we, called this end of the magnet the north-seeking pole.

Current and Flow of Electrons.—Here also our names and the facts clash. For years we thought that the electricity, or whatever it was that we called electricity, flowed through our apparatus from the carbon to the zinc pole. Many convenient rules have been devised and memorized by millions of men using this mental picture of current. Thousands of books con-

tain valuable material and discuss electrical things, talking about current as flowing thus.

If we now, knowing that what moves in the circuit is a number of electrons and that they move from the zinc through our apparatus to the copper pole, change the definition of current, we will create endless confusion.

All the old rules may stand; all our memorized knowledge be perfectly valid and valuable, if we say

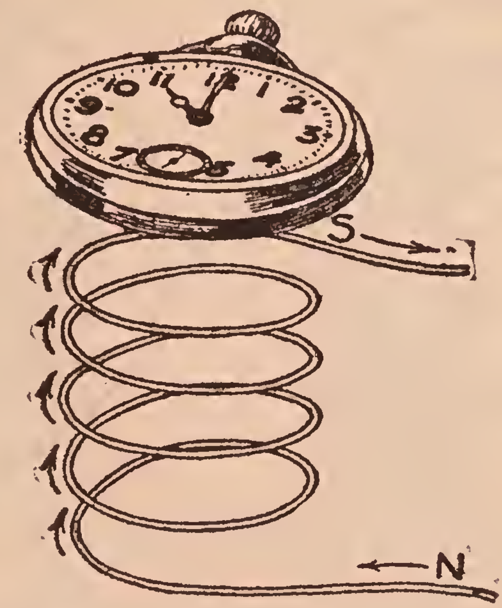

Fig. 52. Watch Rule for Polarity of Magnet.

current when we mean current and flow of electrons when we mean the actual movement of the electrons.

For example: Turn to Fig. 50. I glance at this illustration and say: "The current is flowing from the carbon through the solenoid to the zinc pole. The arrows show the direction of the current. But of course we all understand that this current is caused by a flow of electrons which move through the solenoid from the zinc to the carbon pole."

This should not be confusing. Remember that at the seashore the direction of the undertow is opposite to that of the incoming breakers.

One must be careful to say current when current is meant and to say flow of electrons when that is meant.

The Polarity of a Solenoid.—From Fig. 50 one might deduce the rule that when the current goes through a helix in a corkscrew fashion the nearer end is a south pole.

Watch Rule for Poles.—When the current flows

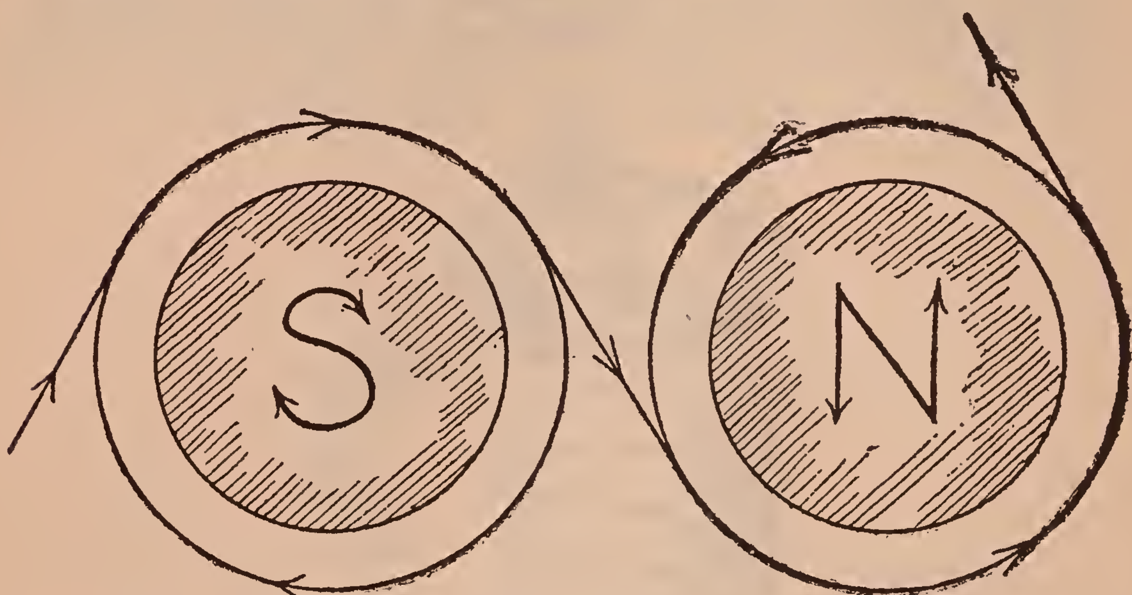

FIG. 53. RULE FOR WINDING HORSE SHOE MAGNET.

around a coil or helix in the direction of the hands of a watch, the nearer end is a south pole. This is shown in Fig. 52. This will enable you to wind bar magnets so as to have the desired pole at a definite end.

Rule for Winding Horseshoe Magnets.—Hold the iron core with the parts which will be the poles facing you. Write on these the letters S and N, as shown in Fig. 53. Using the arrows on the letters as a guide, wind the two limbs or legs of the magnet. You must have the direction of the windings on the two legs reversed else both would have the same polarity.

When the magnet is wound it will have the appearance of Fig. 54. The arrow in both Figs. 53 and 54 show the direction of the current. The electrons are moving in the opposite direction.

What Is a Magnet?—It seems about time to tell exactly what we mean by *a magnet.* Any piece of material which attracts magnetizable bodies and which when freely suspended turns in a north and south line is a magnet.

A magnet has poles and can produce polarity in magnetic substances. By polarity we mean the nature of the magnetism at particular places.

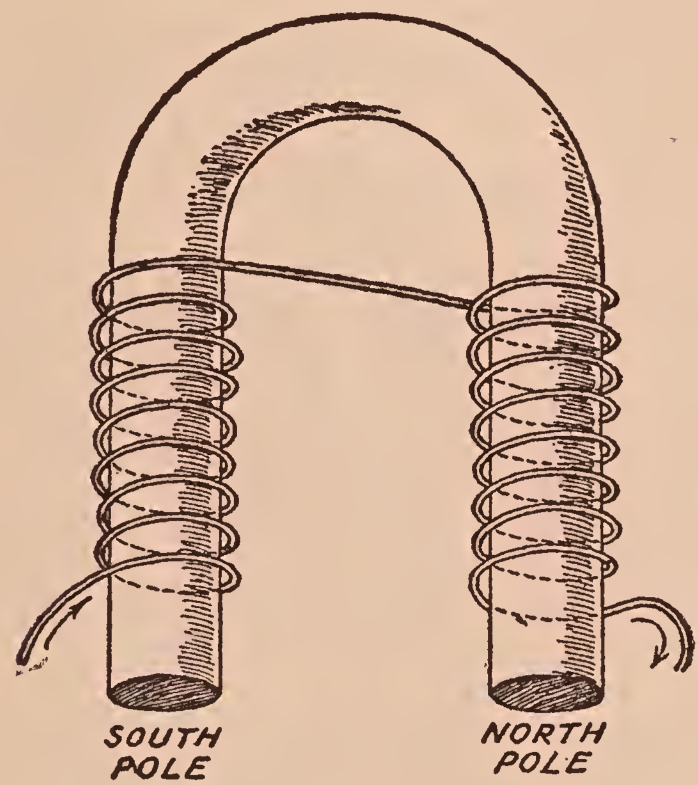

FIG. 54. A HORSESHOE ELECTROMAGNET.

Poles Come in Pairs.—No magnet, no matter how it was made, has less than two opposite poles. Some times in a long thin steel magnet there will be an extra pair of poles between the ones at the ends. This is due to a very hard spot in the steel or a very unequal magnetizing force exerted at different places along the bar. These are called *consequent poles.*

Since the north and south poles of any magnet are but two different aspects of the same magnetic force, you will always find these two poles of equal strength.

Magnetic Substances.—Iron, steel, nickel and cobalt may be magnetized. An alloy of manganese 26.5 per cent, aluminum 14.5 per cent, and copper 59 per cent has magnetic properties as good as cast iron. Besides a few other unimportant alloys, all other materials are equally non-magnetic.

Should you fill the solenoid of Fig. 50 with wood, paper, hard rubber, or paraffin the magnetic force will not be increased. All these materials seem to be equal in their dislike for conducting magnetism.

Cores for Electromagnets.—Should cores of various materials be made for a solenoid, and the strength of the magnet tested, as these are used in turn, the results will be as follows:

Consider the magnetic force due to the solenoid as the standard. Then when a cast iron core is used in it the magnetic force will be 430 times as great. A core of a good grade of Bessemer steel gives a magnet whose force is 1150 times that of the solenoid. A wrought iron core is 1300 times better, and when the very best grade of soft iron is used the magnetic force will be 1430 times as great as that given by the solenoid alone.

PERMEABILITY.—The force that the combination of the current and the coil exerts cannot permeate the air as well as iron. In order to tell a person, quickly and accurately, what results may be expected from cores of different materials we use a number.

We say the permeability is 99. Meaning that the ease with which magnetism passes through the material spoken of is 99 times that of air.

Many of our electrical devices such as bells, induction coils, transformers and all alternating current apparatus using magnetism have iron cores subjected to intermittent magnetism or reversals of the polarity of the magnetism, or both effects. All these must have magnet cores of the very softest iron.

This is not only on account of the high permeability of this material but also because it will lose its magnetism as soon as the magnetizing force is removed.

Should the cores of the magnets in bells, sounders, relays, and transformers retain their magnetic properties after the current is cut off, several annoying things would happen. Their action would be sluggish, instead of quick and snappy, and the magnet cores would become heated.

Retentivity.—The ability to retain some magnetism after the magnetizing force has been removed is called *retentivity.*

Usually this is a very annoying property, but there are places where it is valuable.

The residual magnetism which is left in the magnets of a dynamo or generator when it is standing idle enables the machine to start generating again when it is put into service. If its cores had no retentivity, they would require magnetization every time the generator was started. Were it not for the retentivity of hard steel and the large quantity of its residual magnetism, we could not have permanent magnets.

Magnetizing Force.—The ability of a piece of lodestone or an artificial magnet to impart its properties to a magnetic material I can not explain. There has been so much to investigate during the past ten years that the big scientists have not dug very deeply into this. Perhaps they will leave this for you boys to solve when you are a bit older.

We do, however, know just what to do to make a magnet, and we know what we will get when we use a certain sized magnetizing force.

Ampere-Turns.—One turn of wire carrying a current of one ampere or two turns carrying half an ampere, etc., is what we mean by an ampere-turn. We know that two ampere-turns produce twice the magnetism that one will.

So when you wish to compare two electromagnets, count the turns on one, multiply by the current and you have the magnetizing force. Do the same for the other. If the permeabilities of the cores are the same the magnetisms produced by each will be in proportion to the ampere-turns on each.

Flux.—Magnetism is thought of as flowing like current, and so we speak of the magnetic flux or flow.

LINES.—We must have some unit for flux and so the unit of flux is called a *line*. This name was passed on to us by those who knew less than we do about magnetism. It is a poor name, but since we all know it we continue to use it.

OTHER UNITS.—We have attempted to make people use certain words such as *gauss, weber, maxwell* and density or lines per square centimeter, in talking about magnetism, but at present only engineers and scientists use these names.

Saturation.—When a magnet has about 800 ampere-turns on each inch of its length we find that doubling the magnetizing force does not double the magnetic flux. In fact, for all practical purposes you have wasted the material used and the expense for current, for there is no increase in the flux. None? Well, the increase is so small that practically speaking, there is none.

We call such a magnet saturated. As the material of the core approaches saturation it takes a greater and greater number of ampere-turns to produce equal increases in the magnetic flux.

It is easy to find out that this does occur, and perhaps we can understand this action better if we consider the following experiment:

SATURATION.—*Experiment* 35.—Procure a short, thick rubber band and a bunch of butchers' wooden skewers. Place a dozen skewers inside the band. Prac-

tically no effort is required. Place another dozen in the band. A gentle pressure may be needed as you begin to feel the reluctance of the band to expand.

The next dozen must be pushed in. The following dozen may need strong pressure, in fact you may be compelled to push them in one at a time. Towards the end you will find yourself driving the skewers in with a piece of wood or a small hammer.

Evidently the ease with which the skewers can be placed inside of the rubber band depends on the number that are already there.

Magnetic materials act in the same way when you magnetize them. The more flux in them the greater is the magnetizing force needed to increase the flux.

Theory of Magnetism.—In 1876 Rowland proved that a charge of electricity produced the same magnetic effects as a current. This at once suggested that the magnetic qualities of lodestone were due to the revolving electrical charges in the molecule of the material.

Until more was known about the constitution of the matter, this idea was but a theory which could not stand against the criticisms of scientists who were searching for the truth.

Today we feel quite sure that electrons revolving in the molecules of a substance produce the effect that we call magnetism.

This theory is reasonable. If a coil or a single turn of wire bearing a stream of electrons will produce magnetic effects, it is quite likely that the magnetism of a lodestone is due to streams of electrons, looping the loop, inside of the molecules.

If we accept this theory we can picture to ourselves how a piece of iron may become magnetic.

How Iron Becomes Magnetized.—In the molecules of the iron are some electrons revolving in orbits,

or we might say, looping the loop. This makes these molecules magnetized and gives them polarity.

If the molecules are all jumbled up, as they probably are in a piece of iron, or in fact in any material, then we should expect their polarities to cancel and the mate-

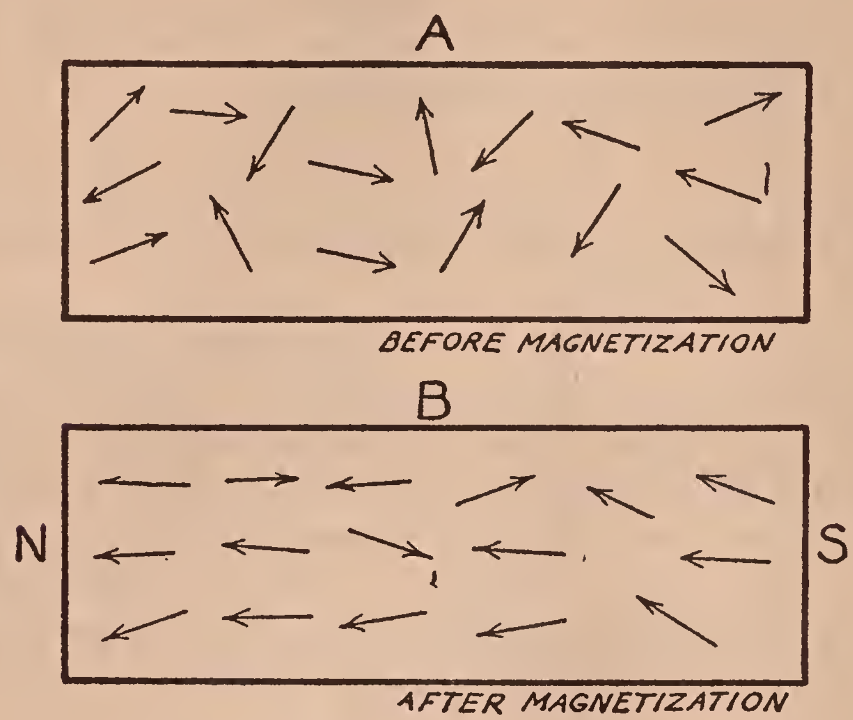

Fig. 55. How Iron Becomes Magnetized.

rial to show no magnetism. Fig. 55 A shows this condition.

When the magnetizing force of the ampere turns of a solenoid act on a bar of iron, the electrons are twisted around until they all revolve in the same direction. All? Well, practically all. Then the polarities are arranged as in Fig. 55 B and the iron becomes a magnet.

The stronger the magnetic force and the greater the permeability of the iron the more molecules are twisted around.

The inherent possibilities of becoming a magnet are all there in the molecules of the iron, but it is the ampere-turns of the solenoid that lines up these conflicting forces and makes the magnet.

The revolving electrons in the molecules of a permanent magnet form ampere-turns which give the magnetizing force utilized to make other magnets by the stroking method. See Fig. 49.

Effect of Breaking a Magnet.—Since every tiny particle of the iron is a magnet and has two poles of

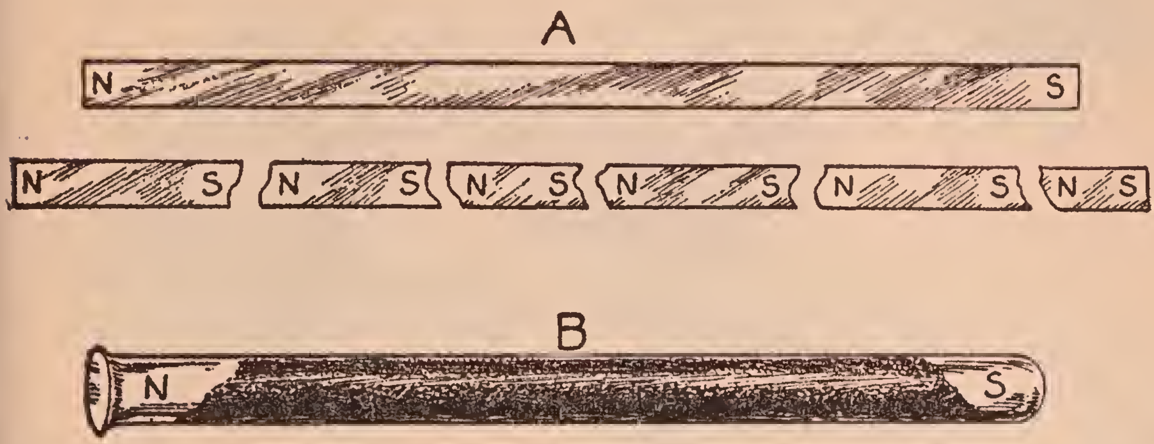

Fig. 56. Breaking Magnets.

opposite polarity, the effect of breaking a magnet should be to produce two magnets. This is exactly what happens. Fig. 56 A is a picture of what actually happened when a magnet was broken.

Experiment 36.—A test tube filled with iron filings when placed in a solenoid becomes a magnet. If carefully handled it holds some of the magnetism, but when shaken all the little magnets get jumbled up and their polarities cancel. Fig. 56 B shows how to arrange the filings in the test tube.

Magnetic Field.—The space throughout which the magnetic force of a magnet can be detected is called the *field* of that magnet.

All magnetic substances become magnetized when in a magnetic field. We say the magnetism is induced in these materials and the process is called *magnetic induction.*

MAGNETIC INDUCTION.—*Experiment* 37.—Arrange a magnet, a strip of wood and a piece of soft iron as shown in Fig. 57. The magnetic field of the magnet, passing through the soft iron, makes it a magnet and

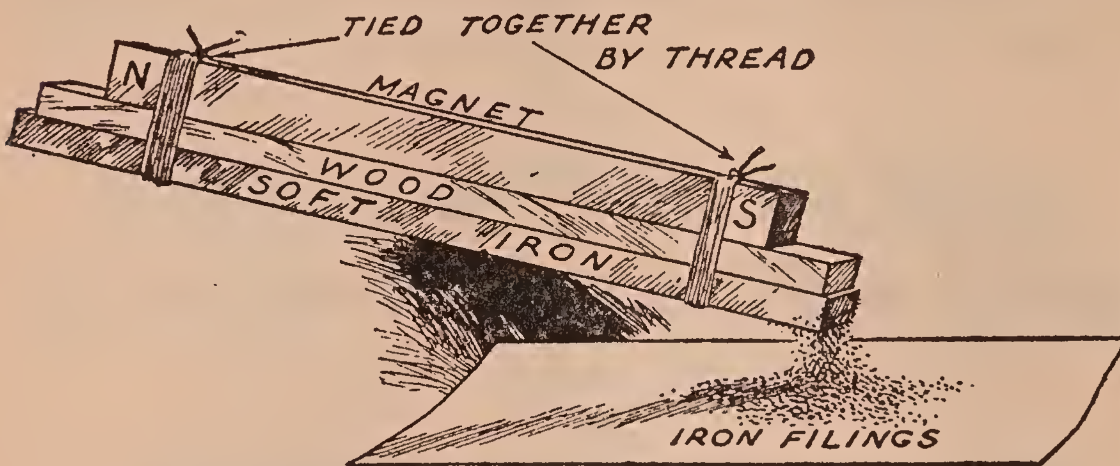

FIG. 57. MAGNETIC INDUCTION.

it will attract iron filings. Notice that the soft iron and the magnet are not in contact and that the wood is a non-magnetic material.

Experiment 38.—Suspend some small pieces of soft iron, such as tacks, from a magnet pole. Then, as

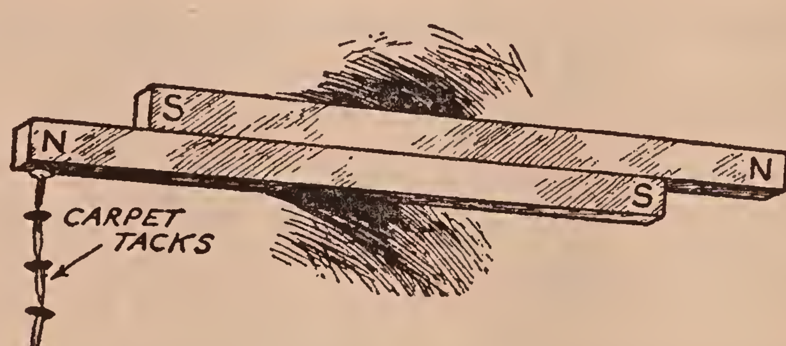

FIG. 58. WHEN TWO POLES MAKE NO POLARITY.

shown in Fig. 58, place another magnet over the first one. Arrange the poles in the position shown.

Now slowly push the top magnet along. As the two opposite poles approach, the tacks will fall off. You

have neutralized the polarity of these poles and thus destroyed the magnetic field. The tacks are no longer magnetized and will not attract each other nor the big magnet.

Perhaps you would rather have me say that the big magnet no longer attracts the tacks. The action is a

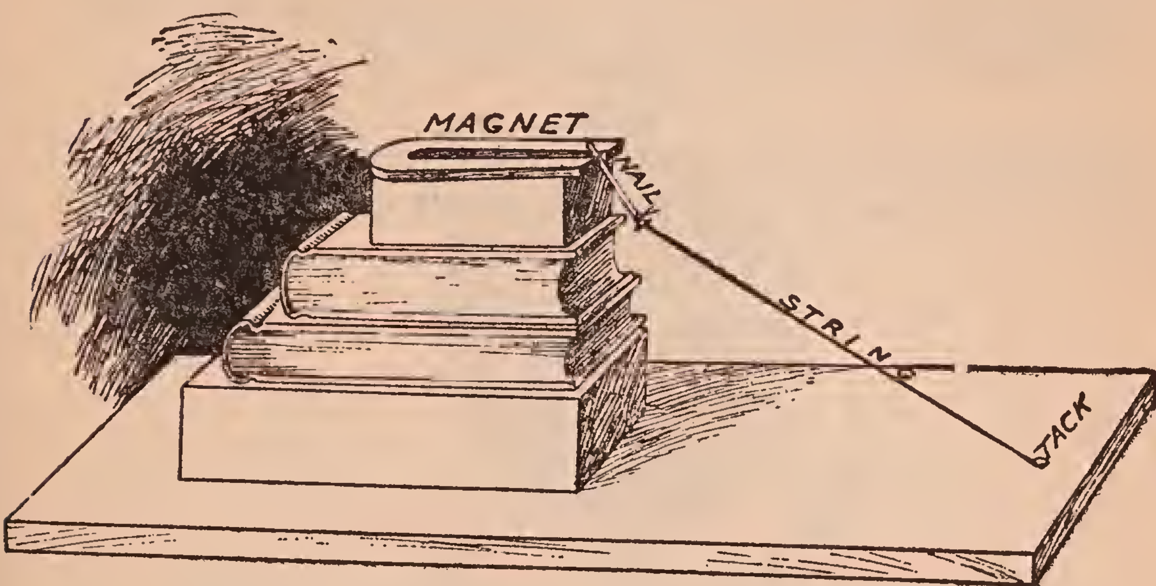

FIG. 59. FORCE DUE TO MAGNETIC FIELD.

mutual one, for each attracts the other. A magnet only attracts iron or steel by first magnetizing it by induction, and then the two magnets attract each other.

Experiment 39.—An experiment which shows the lifting power of a magnet due to its magnetic field is shown in Fig. 59.

Arrange a strong horse shoe permanent or electromagnet and a nail as shown. Place two slips of paper on each side of the nail, between it and the poles of the magnet. Thus there can be no actual contact between the nail and the poles.

You will be able to suspend the nail in the air as shown. The string is to prevent the nail from swinging down against the support. Use a light string or thread so as not to add weight to the nail.

No Insulator for Magnetism.—There are many materials which have low permeability; that is, do not conduct magnetism well, but there is nothing that refuses to conduct magnetism. Hence there is no insulator for magnetism, such as rubber is for current electricity.

Magnetism goes through everything, as is shown very clearly by the following experiment.

Experiment 40.—Suspend a small magnet and let it come to rest in the north and south position. Place

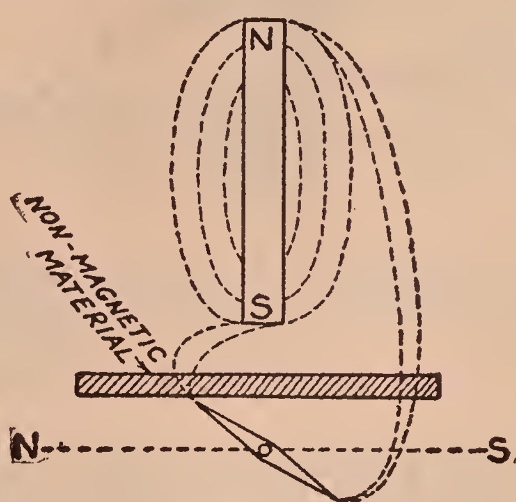

FIG. 60. MAGNETIC TRANSPARENCY.

beside it a piece of some non-magnetic material or this book that you are reading.

Then as shown in Fig. 60 bring up a magnet. The suspended magnet will be moved. The dotted lines show the lines along which the magnetic action or flux exerts its force.

Although you can not keep magnetism back by the use of insulators, you can keep it out of places where it is not desired by the use of conductors. I know that this sounds queer, but it is true.

Side Tracking Magnetism.—When a piece of iron is placed in a magnetic field, the iron, due to its

superior permeability, concentrates all the magnetic flux into itself. Hence the surrounding space loses almost all its magnetic force.

You can practically clear a space of magnetism by completely surrounding it with a thick wall of soft iron. The iron conducts so well that the magnetism will go

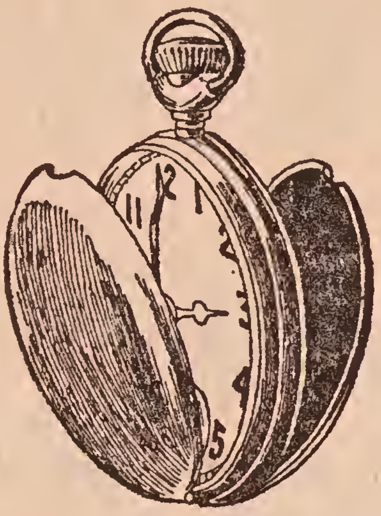

Fig. 61. Protecting a Watch from Magnetism.

through a long path of iron, rather than a short path of air, brass, gold and such materials.

If a watch is placed in a magnetic field its hair spring and main spring will become magnetized and the watch will not keep correct time.

Protecting Watches.—Enclosing the watch in a soft iron case protects the watch by side tracking the magnetism, as in Fig. 61. The magnetism will go through the iron case and thus around the watch. There will be no magnetic field inside the case, although the iron case be as thin as a 64th of an inch.

Experiment 41.—Arrange a suspended magnet and a thick plate of magnetic material, the thicker the better. The permeability should be high, so iron is better than steel. I suggest a laundry iron, waffle iron, or griddle as handy things. When the magnet is brought up the

flux passes through the iron but not across it and out into the air. So the suspended magnet is not affected. Fig. 62 shows the path of the magnetic flux. Hence

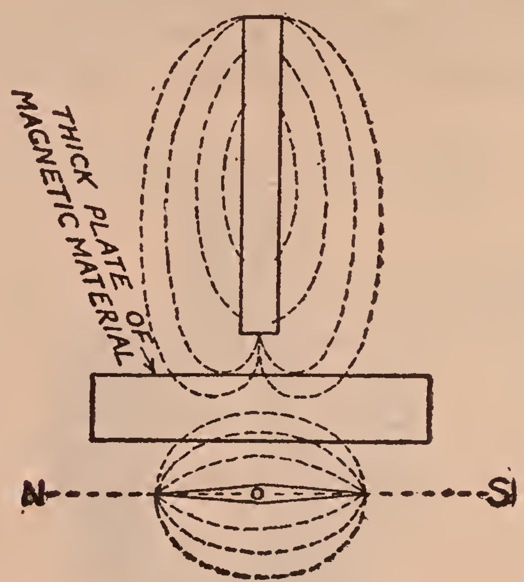

FIG. 62. SHIELDING FROM MAGNETISM.

there is no magnetic field beyond the iron coming from the magnet.

The Compass.—The practical use of a freely suspended magnet as a guide in navigation is greatly interfered with by the fact that the compass does not point to the true north.

The suspended needle does not point to the spot where the earth's axis passes through the surface of the earth, but to a point to the south of this.

The magnetic north pole is in the Boothia Peninsula of the Dominion of Canada, 1300 miles south of the earth's north pole and directly north of the central part of the United States.

DECLINATION.—The declination of the needle is the angle between the indication of the compass and the line to the true north.

There are *agonic lines* or *lines of no variation* on the earth's surface, along which the compass points to both

the north magnetic and geographic poles. At all other places the indication of the compass must be corrected to obtain the direction of the north pole.

The simplest form of compass is a light magnet floated upon a cork. The magnet will turn into a magnetic north and south position. See Fig. 63A.

Dip.—*Experiment* 42.—Arrange two steel knitting needles as shown in Fig. 63 B. The cylindrical needle on the edges of the glasses causes very little friction.

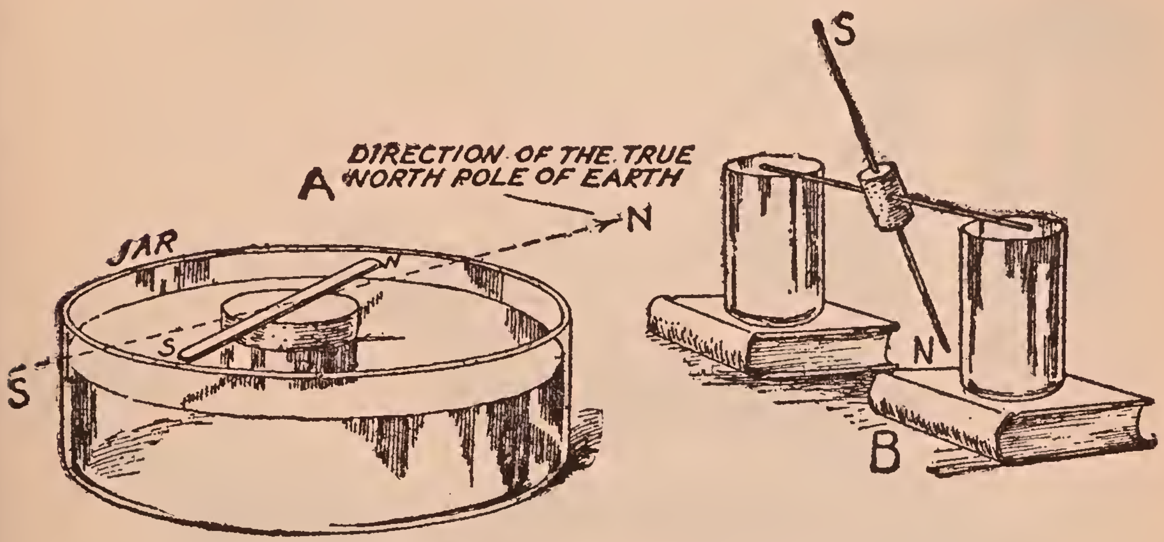

Fig. 63. Declination and Dip.

Adjust the position of the needle until you have an exact balance. Then without disturbing the position of the needles magnetize the one not used as an axle. Upon replacing them on the glasses the balance will be destroyed. In New York the north end will dip and the magnetized needle take the position shown in Fig. 63 B. The angle between the needle and the horizontal plane will be 70°.

In the Southern hemisphere the south end of the needle will dip.

The Earth a Magnet.—The declination and dip of the needle are due to the earth acting like a huge

magnet, with two opposite poles. A large steel ball when magnetized will act on a tiny compass exactly as our earth acts on our compasses.

Current Acts Magnetically.—A straight wire carrying a current has an effect upon a magnet, which you will remember better if you see its results.

THE EFFECT OF CURRENT ON A MAGNET.—*Experiment* 43.—In a basin of water float a magnet on a cork.

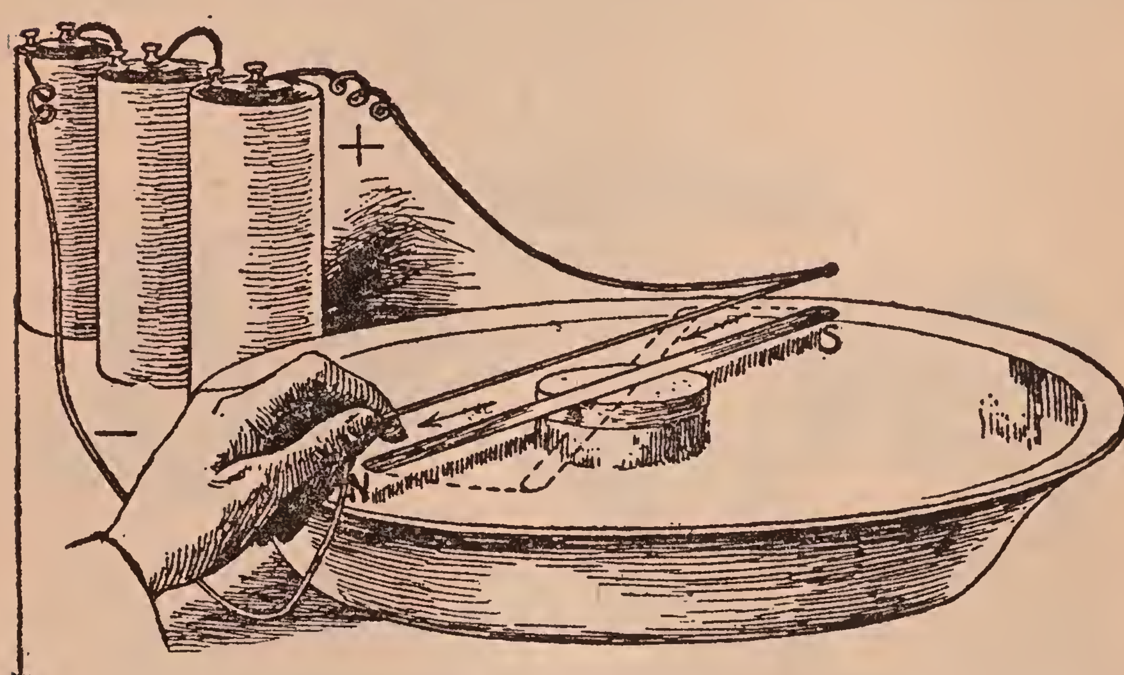

FIG. 64. EFFECT OF CURRENT ON A MAGNET.

When it has swung into the north and south line, bring a wire carrying current directly over it. The wire is to be attached to the battery as indicated in Fig. 64. Now the current (not the electrons) flows from the south to the north and over the magnet. You will find that the north end of the magnet swings towards the west.

SNOW RULE.—To remember this action between a current and a magnet use the word **SNOW**. This word is taken from the sentence: "When the current flows

from the South to the North Over a magnet the north end swings to the West."

Principle of the Galvanometer.—A consideration of the action in Experiment 43 will show you that if a wire carrying current is carried over and under a magnet, it will be urged in the same direction by each part of the current. For the current flowing to the north and over the magnet twists it in the same direction as a

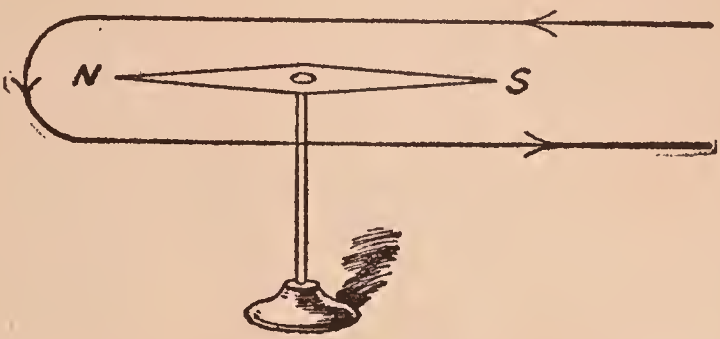

Fig. 65. Principle of the Galvanometer.

current in the opposite direction on the opposite side, that is, under the magnet. See Fig. 65.

Weak currents may make a strong effect on a magnet if many turns of wire are wound into a coil and the magnet suspended in the coil. For the exact arrangement see Fig. 7.

Further Experimentation.—With a few magnets, both permanent and electromagnetic types, needles, iron filings and a sheet of cardboard any ingenious boy will have lots of fun. More than that, you will find out what can and can't be done with magnets. Beware of saying that something can not be done until you try it.

You would not think that a. c. would magnetize a horse shoe electromagnet. If you have a. c. in your home, use the 110 volt control panel to attach the magnet to the supply. You will find that the magnet will support weights. The poles are continually changing, but any pole will attract magnetic substances.

CHAPTER X

DYNAMOS, MOTORS AND TRANSFORMERS

Electromagnetic Induction
- Inducing Current
- Experiment 44

Rule for Direction of Induced Currents
Facts About Induced Currents
A Simple Alternator
A Simple Direct Current Generator
- The Commutator
- The Armature
- Armature Cores
- The Fields

The Voltage of a Dynamo
Voltage Regulation in A Power Plant
Current Capacity
Motors
- What Makes a Motor Go
- The Work of the Commutator

The Power of a Motor
- Rule for Power
- Rule for Speed
- Rating of a Motor
- Output
- Intake
- Efficiency
- Current Taken

Shunt Motors
Series Motors
A. C. Motors
Series Motors Again
The Universal Motor
Induction Motors
Reversing a Motor
Boosters
Dynamotors
- Motor-dynamos

Rotary Converter

CHAPTER X

DYNAMOS, MOTORS, AND TRANSFORMERS

Dry cells, wet cells, storage batteries and all such devices for sending out streams of electrons are too small to be used as commercial sources of power.

If the water supply for your home were delivered daily in buckets you would be unable to lead a modern life. In a similar way the widespread use of electricity in our daily life is made possible only because we have electricity at the turn of a switch, just like water at a faucet.

To properly and economically operate the many electrical appliances in our homes, offices and factories we need lots of electrons at high pressure. Cells will not do. We must utilize the principle of

Electromagnetic Induction.—When a magnetic field and a conductor move toward or away from each other there is produced in the conductor a force that moves electrons.

This relative motion of the field and the conductor may be accomplished in several ways.

1. In very high voltage a. c. generators the magnetic field is moved and the conductors are stationary.
2. In d. c. generators the conductors are moved, while the magnetic field remains at rest.

This is because the electrical engineer has found it better to design the a. c. and d. c. dynamos, or generators, as they are usually called, in these ways. It is not because the different ways produce different kinds of current.

Before you can understand the action of a generator you must firmly fix these truths in your mind.

1. Motion that carries a conductor across a flux produces current in the conductor.

2. The direction of the current depends upon the polarity of the flux cut and the direction of the motion of the conductor across this flux.

I am speaking of flux as if a definite something flowed from the north pole to the south pole of a magnet. Perhaps nothing does, but the process of electromagnetic induction acts as if something was cut by the passing of the conductor across it.

Let us get our ideas straightened out by performing this experiment.

Inducing Current.—*Experiment* 44.—Wind a small cardboard tube or a form about two inches square with 100 turns of No. 30 cotton-covered wire. Place it as shown in Fig. 66 in the field of an electromagnet. Connect this coil to a galvanoscope. Be sure that the coils A and B, often used with this galvanoscope, are *not* in the circuit.

When you suddenly draw the coil out of the magnetic field the galvanoscope will give a momentary deflection. If you suddenly thrust the coil into the field the galvanoscope will give a momentary deflection, but in the opposite direction from before. The arrows in Fig. 66 show the direction of the current when the coil is thrust into the magnetic field.

The size of the deflection depends on the speed of the motion. If you will now unwind half the coil and repeat the experiment you will find that the deflection is half its previous value.

By this experiment you have learned enough to see that a rule might be written to predict the direction of the current when the circumstances are known.

Rule for the Direction of Induced Currents.—Hold the thumb and first two fingers of the right hand so that the thumb, the first and the middle fingers

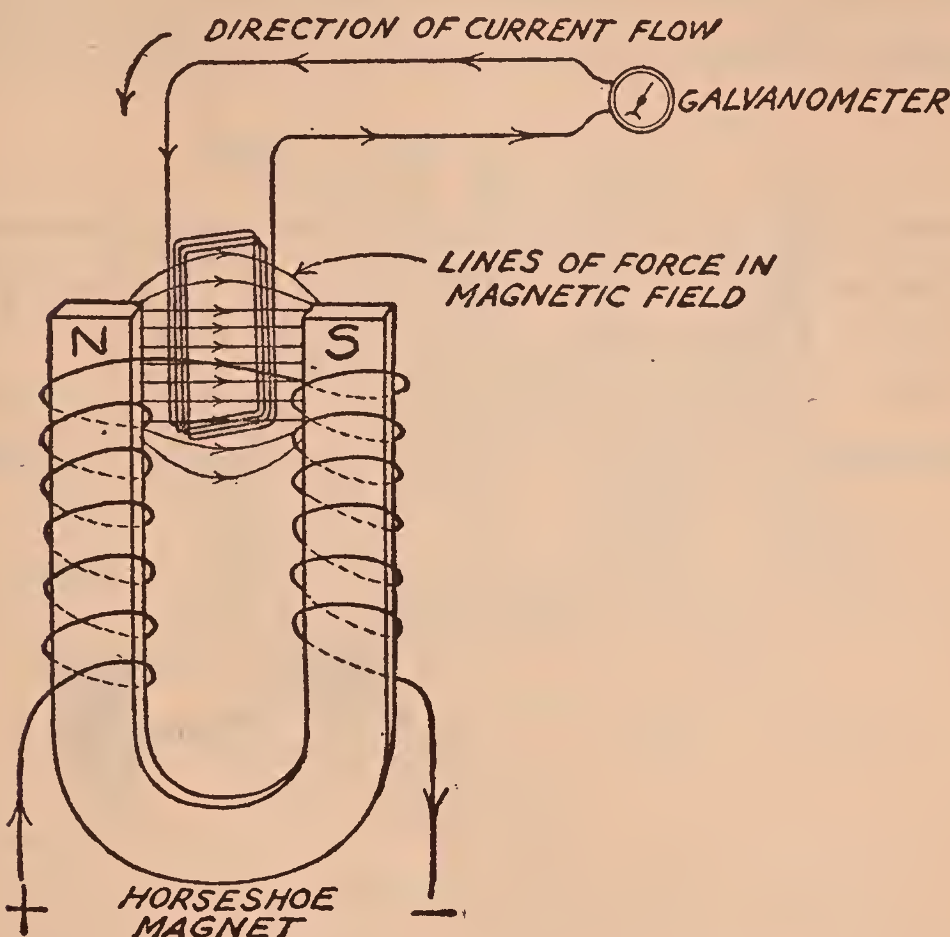

Fig. 66. How Current is Produced by Magnetic Induction.

are at right angles to each other. Fig. 67 shows exactly how to do it.

Let the first finger point from the north pole to the south pole of the magnet, that is in the direction of the flux. Let the thumb point in the direction of the motion of the conductor. Then the center finger will point in the direction of the induced current.

Memorizing this rule is made easy by fixing the mind on First finger for the flux and Center finger for the current.

Should you want a rule for the flow of the electrons, then use the same rule with your left hand.

The apparatus shown in Fig. 66 may be used to show the following.

Facts About Induced Currents.—1. When a wire moves in a circle, cutting through the flux between two magnet poles, the induced current is reversed twice a

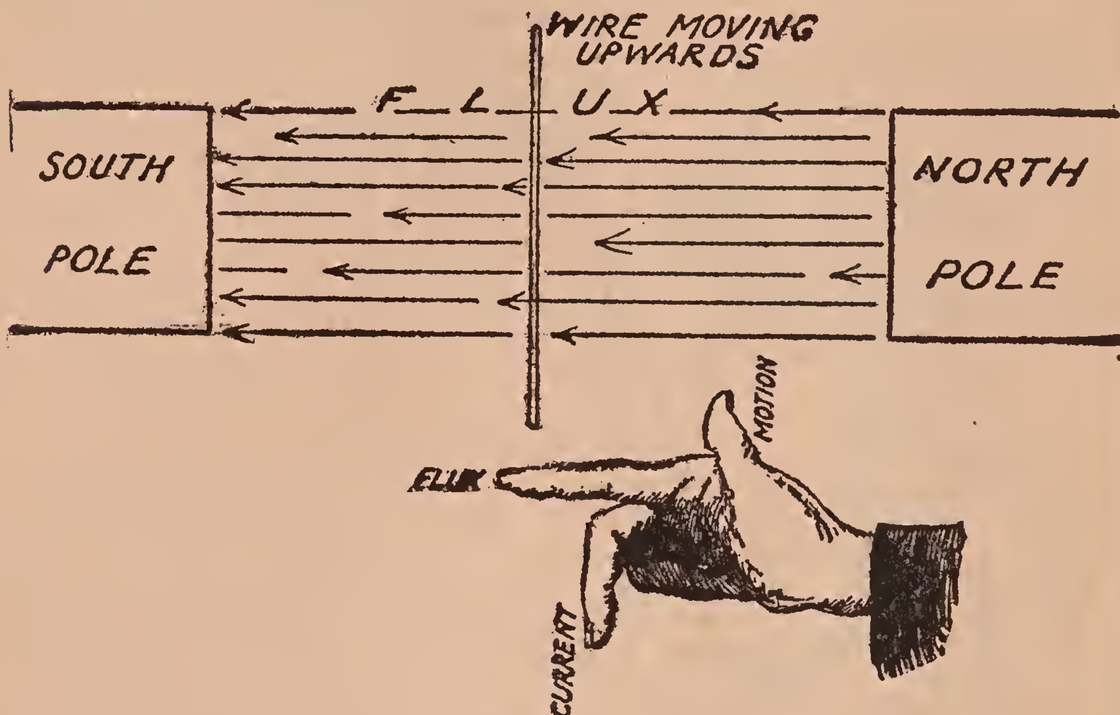

FIG. 67. RIGHT-HAND RULE FOR INDUCED CURRENT.

revolution. The current generated is an alternating current.

2. The swifter the movement of the wire the greater the current.

3. The stronger the magnetic field the stronger the current.

A Simple Alternator.—The alternating current generator or dynamo is usually called an alternator. In its simplest form it consists of a field magnet and an armature. The armature consists of the winding and the core. The core is of soft iron, thus making the path, for the flux from pole to pole of the field magnet, more permeable.

To make the picture clearer, in Fig. 68 we have

omitted the core on which the wire of the winding is wound and have shown but one coil of wire of the winding. But since every wire does the same thing and has the same things happen to it, one wire will be enough for our explanation.

The situation shown in Fig. 68 is that of the wire

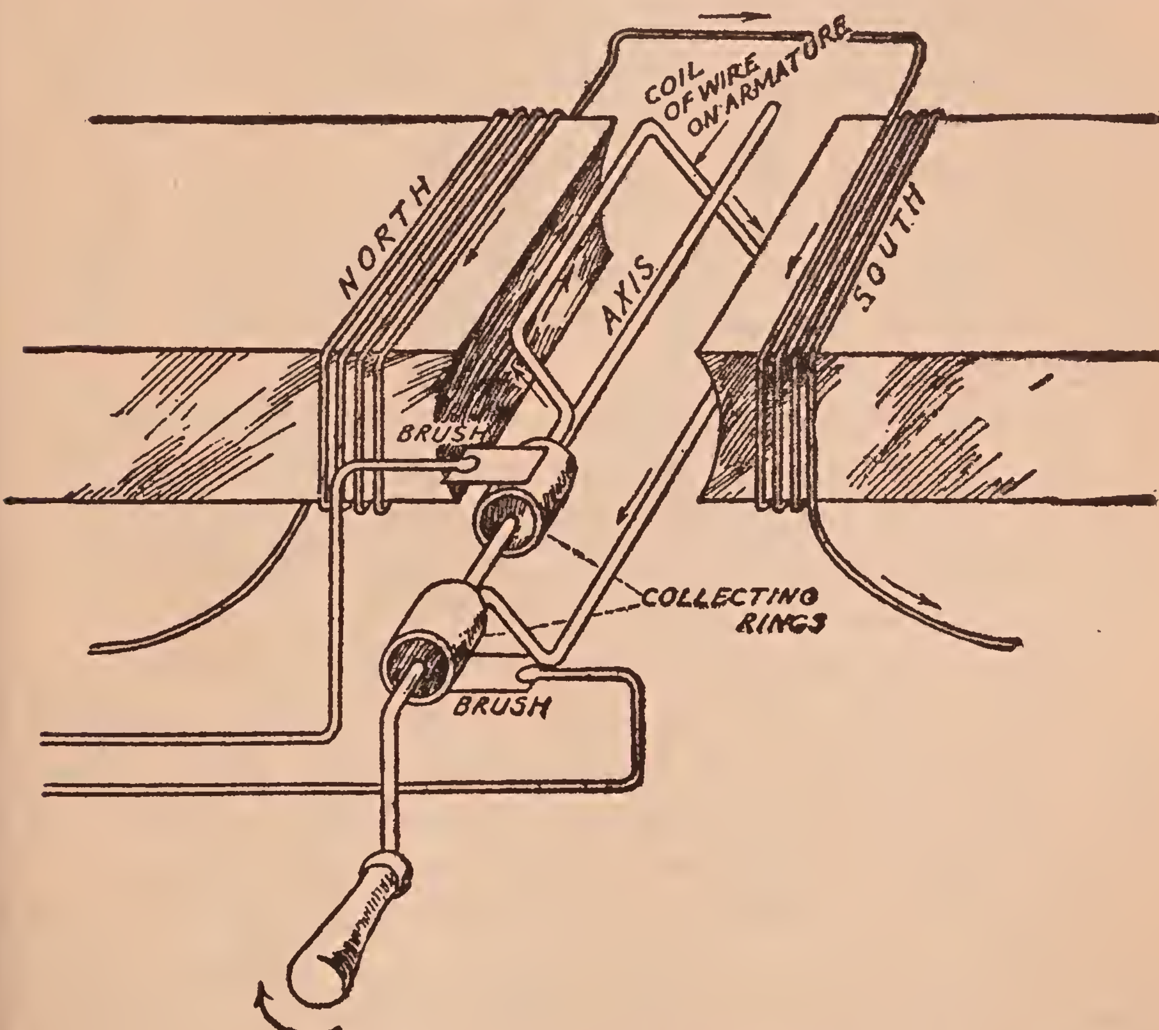

Fig. 68. A Simple Alternator.

on the left hand side of the winding having just completed a passage across the face of a north pole.

By remembering our right hand rule we could predict that a current would be flowing along this wire in the direction shown by the arrow.

On the right hand side of the armature is a wire that has just passed across or *cut,* as we say, the flux entering the south pole.

Remembering that the flux is said to flow from the north pole to the south pole, by using the right hand rule, we expect the current to flow in the direction of the arrow.

Considering the two wires as a loop you will see that the current tends to flow around this loop.

If two cylinders of copper are mounted on the axle of the armature and these two cylinders are insulated from the axle or shaft and from each other, we may use these as sources of current.

To do this solder one end of the coil of wire to one of the cylinders or collecting rings, as they are called, and the other end to the other collecting ring. All as shown in Fig. 68.

Arrange to have the wires of the outside circuit end in flat pieces of carbon or copper called brushes. These brushes held firmly to the frame of the generator, slide on the collecting rings and allow the current to flow out and into the alternator.

Notice that the wire attached to a collecting ring is alternately going up across the flux on one side and then down across the flux on the other side. Thus this collecting ring is alternately sending electrons out of the machine and then pulling them back again.

In such a machine as pictured here the current generated must be an alternating one. Since no dynamo or generator has any different internal arrangement, all generators are alternating current generators.

Don't get excited. I mean it. A direct current generator is an alternating current generator with a built in device for reversing the connections of the armature to the outside circuit at the proper time, so that the outside circuit receives direct current.

A Simple Direct Current Generator.—In Fig. 69 is shown the same machine that we have been discussing with the collecting rings removed and a new device substituted for them.

This device is called a *commutator*. It is really nothing more than a rotating switch.

THE COMMUTATOR.—In its simplest form as shown in Fig. 69, it consists of two copper strips or segments in the shape of half cylinders. These are mounted as shown, and insulated from each other and from the

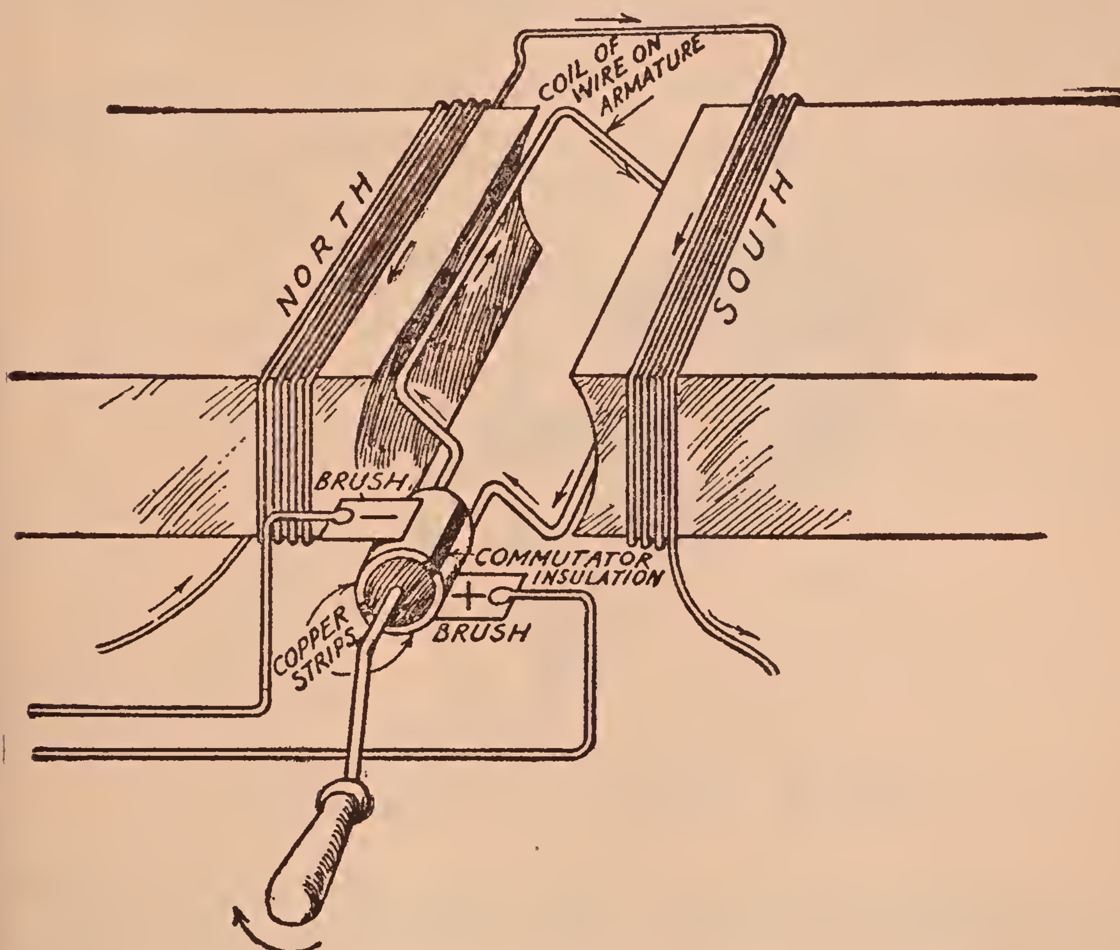

FIG. 69. A SIMPLE DIRECT CURRENT GENERATOR.

shaft of the armature. The coil of wire has each end attached to one of these commutator segments.

The situation pictured is where the current is flowing out of the right hand brush. Hence this is called the positive brush.

Remember that the brushes are stationary and that the commutator revolves with the armature and its windings (coils). You will observe that when the armature wire, now in front of the south pole, moves

over in front of the north pole, and the current in it reverses, it will then be connected by the commutator to the other brush.

In this way the a. c. generated in the armature winding is rectified or commutated by this rotating device, so that current always flows out from one brush and flows in by the other. Thus the outside circuit is served with d. c.

THE ARMATURE.—In actual machines, having but one coil on the armature would result in an uneven

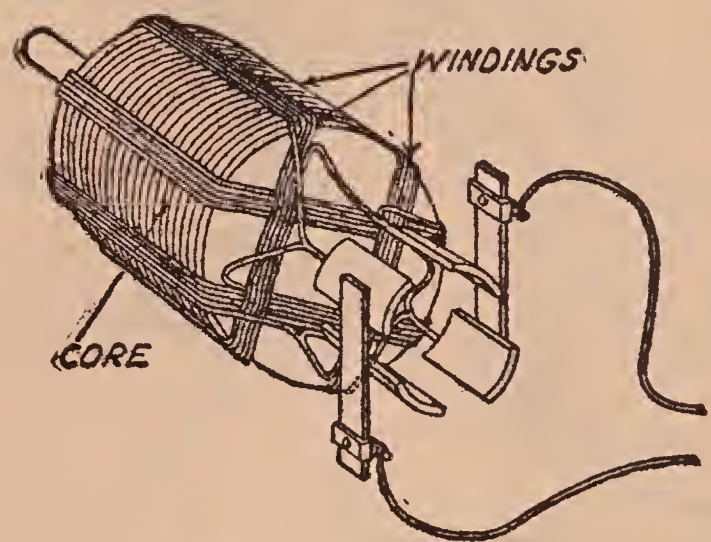

FIG. 70. DIAGRAM OF AN ARMATURE.

or pulsating e. m. f. Hence many coils of several turns each are wound on the core and each is connected both to its neighbor and to a pair of commutator segments. Fig. 70 shows an armature with two coils. For convenience in winding, each coil was put on the core in two parts.

Each coil is connected to a pair of commutator segments.

ARMATURE CORES.—The soft iron core which supports the windings has additional functions. It must revolve the wire through the flux against the force which the flux exerts to hold these windings stationary. Hence these cores are *slotted,* and the armature coils

are wound in these slots. It must also furnish a very permeable path for the flux from pole to pole. Hence it is of *very soft iron.*

But this is not all. The core is not only magnetized by the fields but as the core revolves its magnetic polarity is continually reversing. To prevent excessive heating under these circumstances the core is made of *sheets* of soft iron. We say that the cores are laminated.

THE FIELDS.—The magnets producing the magnetic flux of a generator are called *field magnets* or simply the *fields.* Note that the alternator requires direct current in the coils of its field magnets, just as a d. c. generator does.

The field current for an alternator is supplied by a separate d. c. generator or from a commutator mounted on its own shaft which rectifies enough current to serve the field magnets.

In d. c. generators, two wires lead from the brushes to the field coils. This type of generator is called a *shunt* generator to distinguish it from the very rare type called the *series.* In this latter type all the current going through the external circuit also passes through the fields.

The Shunt Dynamo.—The shunt generator tends to give a steady e. m. f. because the current flowing in the main or external circuit has very little influence on the current in the field circuit. Each is supplied by the e. m. f. of the machine, but they are separate, independent circuits. Fig. 71 shows the electrical connections of a *shunt generator.*

The Voltage of a Dynamo.—The e. m. f. of a dynamo depends on the number of turns of wire on the armature that are connected in series, on the speed with which these wires cut the flux and on the quantity of flux, that is the strength of the magnetic field. Increasing any one of these increases the e. m. f.

Since the armature winding offers some resistance, as soon as the dynamo delivers current there will be a *drop* in the armature winding and the voltage at the terminals of the dynamo will be less than its e. m. f.

Voltage Regulation in Power Plants.—To keep the voltage up to the proper value a rheostat is used

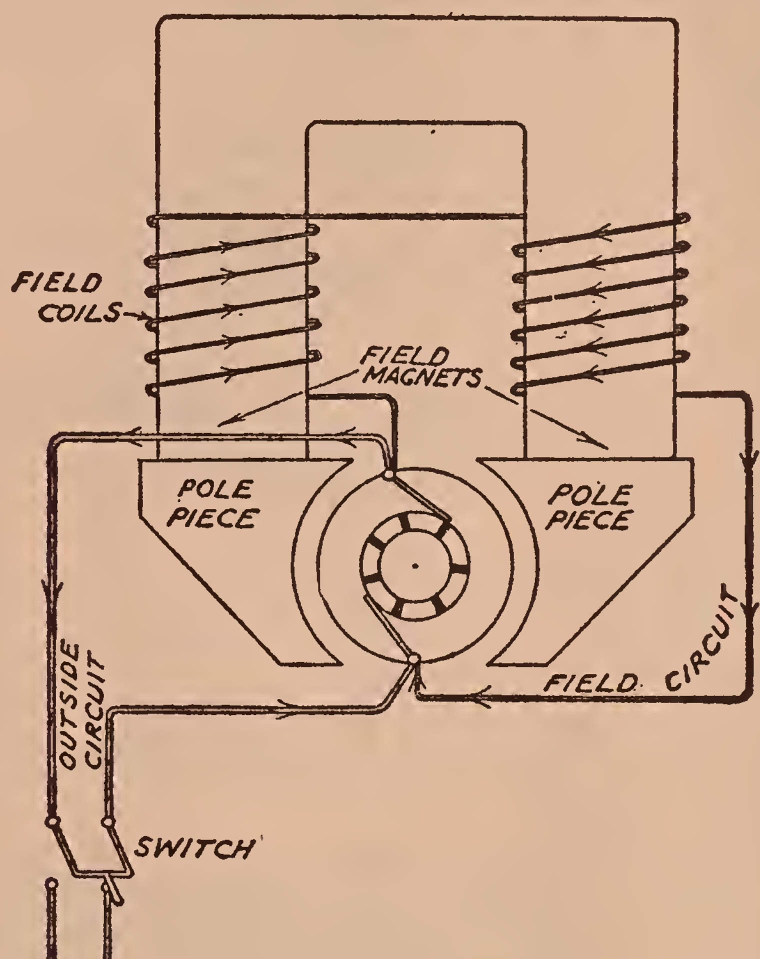

FIG. 71. DIAGRAM OF CONNECTIONS OF A SHUNT DYNAMO.

in field circuit. This resistance is cut out of the circuit, by the man in charge of the dynamo, a little at a time, so that although the drop increases with the load, the increased field strength will keep the voltage constant.

Current Capacity.—An armature wound with small wire cannot carry a heavy current without overheating. The current capacity is thus determined by

the current the armature can carry with an increase of temperature of not over 90° Fahr. It has been found that it is not safe to operate a dynamo at a temperature higher than 175° Fahr.

Remember that you may draw any current you please from a dynamo. The e. m. f. is fixed by the design of the machine but you regulate the current by changing the external resistance. Every time you turn on a lamp or a toaster, since they are in parallel, you are lowering the resistance of the circuit and thus the e. m. f. is able to produce a greater current.

Our demands for current from a certain dynamo must be regulated by the knowledge that too much current will burn the insulation from the wire on the armature, and thus cause need for an expensive repair.

Motors.—We have seen that like poles repel and unlike poles attract each other. This force is increased as the strength of the poles increases.

If we could arrange one magnet on a pivot between the poles of a stationary magnet the pivoted magnet would turn until the poles were in a straight line.

Suppose the dynamo shown in Fig. 69 is connected to a d. c. source of power. The armature would make half a revolution and then stop. There is a way of winding an armature so that it will make a complete revolution and keep on revolving as long as it is served with electrical power.

Wind the armature with two coils at right angles to each other. Connect these coils to commutator segments as shown in Fig. 72.

If the machine is in the position shown in the illustration, the current will enter through the + brush to commutator segment C, thence into coil 1 on the armature. Passing through the turns of this coil the current will leave by commutator segment D and the brush back to the source of power. At the same time the field coils have been excited, as we say, and we

have on the field magnets north and south poles as indicated.

Coil 1 makes the soft iron core of the armature upon which it is wound, a magnet. Now the ends of the hole about which a coil of wire is wrapped are the

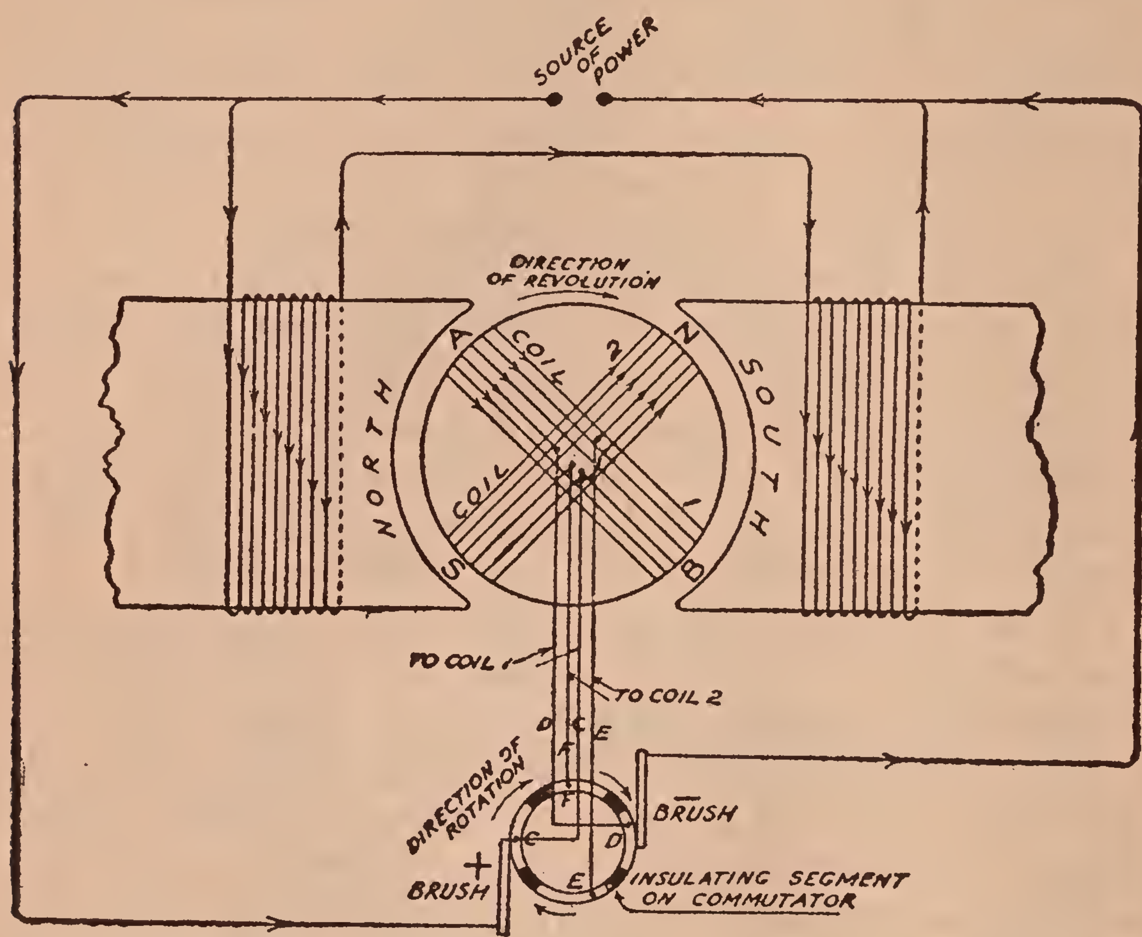

Fig. 72. Diagram of a Shunt Motor.

magnetic poles due to that coil. When that hole is filled with a core which projects out of the coil, then the poles move out on the core towards the ends of the core. This is shown in Fig. 73 where you see the position of the poles of a solenoid, and where they are on a magnet like a field magnet of a dynamo or motor.

There is also shown how, on an armature core, the poles are on the sides of the core, because the sides

of the core are also the ends of the hole inside the coil.

If you will now return to Fig. 72 you will understand why current through Coil No. 1 produces magnetic poles on the armature core at N and S.

WHAT MAKES A MOTOR GO.—Things being as they are pictured in the illustration the armature will revolve in the direction shown by the arrow until the armature and field poles are opposite to each other. We can rely on the momentum of the moving armature to carry it around so that the N and S poles will arrive at the places marked B and A. Then all tendency to revolve ceases.

THE WORK OF THE COMMUTATOR.—Let us not forget that the commutator is fastened to the armature and so turns with it. Thus by the time the poles N and S have arrived at B and A, commutator segments E and F are connected with the brushes. Hence the current is cut off from Coil No. 1 and flows through Coil No. 2.

But Coil No. 2 is now in the place where Coil No. 1 used to be and so Coil No. 2 places magnetic poles at the points marked N and S. Thus a new attraction is created between the field and the armature poles.

Thus the separate coils on the armature and the action of the commutator continually form a north pole at N and as it is attracted to the south pole of the field magnet, they move it suddenly back to the point N.

The Power of a Motor.—To make a motor powerful we wind the armature with many small coils connected to as many pairs of commutator segments. We permit each coil to form the magnetic poles only when it is in the most advantageous position. We also make the field flux as large as possible.

RULE FOR POWER.—The product of the field and armature magnetisms indicates the power of the motor.

Rule for Speed.—The stronger the armature magnetism the faster the speed, the weaker the field magnetism the faster the speed.

Rating of a Motor.—The amount of horse power

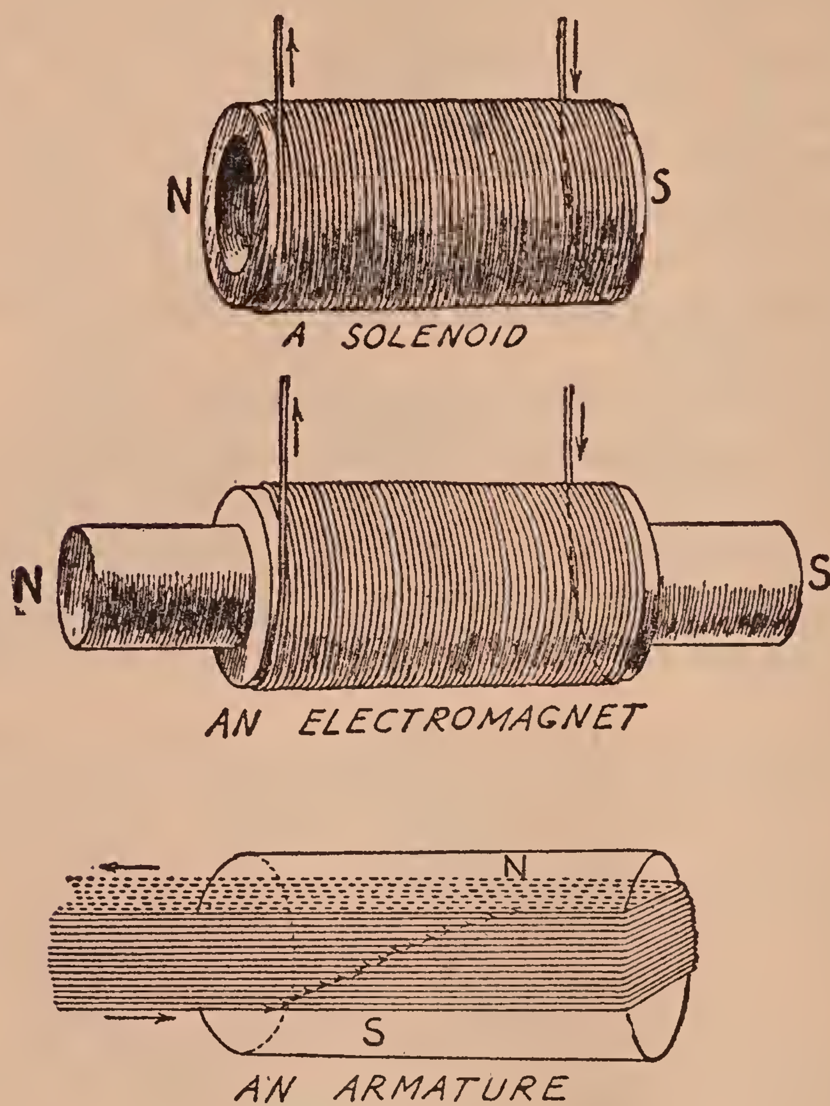

Fig. 73. Poles of a Solenoid and a Magnet.

that a motor can deliver depends on how hot it gets due to i^2r losses while it is working.

The horse power which it can deliver continuously without getting hotter than 175° Fahr. is the rating of the motor.

If you buy a ⅛ H. P. motor and while delivering

full rated power it heats up to 200° Fahr., then that manufacturer was too optimistic. You would not be wise to so load it. Motors are supposed to be capable of standing a 25% overload for 3 hours with no damage to the machine.

OUTPUT.—A 1/8 H. P. motor is rated on its output. Due to losses it will take more than 1/8 H. P. from the line.

INTAKE.—Since 746 watts are equivalent to 1 horse power, the 1/8 H. P. motor must take 746 x 1/8 or 93.3 watts from the line at 100% efficiency.

EFFICIENCY.—Dividing the output by the intake gives the efficiency, when of course both are expressed in the same units. Hence knowing the output we divide it by the efficiency to get the intake.

Remember that in all problems efficiency is expressed as a decimal fraction not as a percentage.

The 1/8 H. P. motor gives out 93.3 watts. At 70% efficiency it must have an intake of, 93.3 ÷ .70 which is 137.7 watts.

CURRENT TAKEN.—The current needed to supply 137.7 watts will depend on the voltage of the supply lines.

Since watts are figured by the product of the amperes and the volts, then the watts divided by the volts will give the amperes. Thus 137.7 watts delivered at 110 volts requires a current of 137.7 ÷ 110 or 1.25 amperes.

Shunt Motors.—The motor that was described so fully and the diagram of its connections given in Fig. 72 was a *shunt* motor. This name shows that the armature and field circuit are shunts on the main or external circuit. Fig. 74 may show this more clearly.

The tendency of a shunt motor is to operate at a steady speed. For this reason it is the best motor for use in factories to drive machinery.

Series Motor.—When the armature and the field coils are in series, we have a motor willing to move at any speed and very powerful at low speeds. These two qualities make it very valuable for traction, mean-

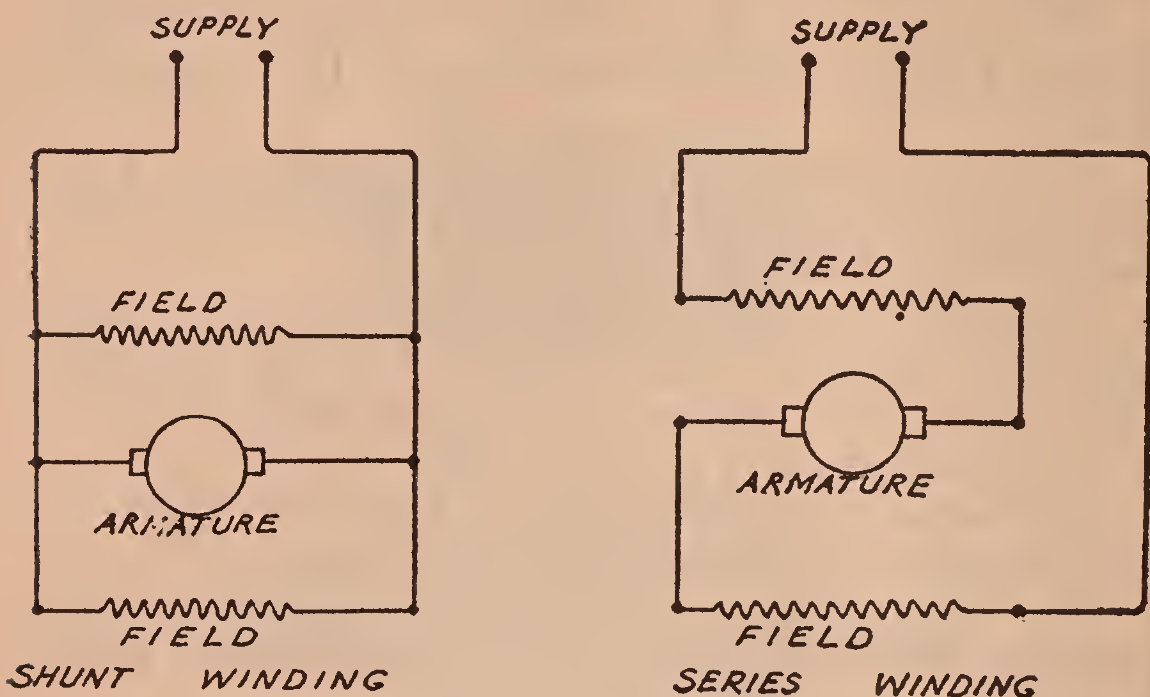

FIG. 74. HOOK-UPS FOR SHUNT AND SERIES MOTORS.

ing electric railway use, and for hoists and elevators. For the connections see Fig. 74.

A. C. Motors.—I have assumed that only d. c. was to be used in the two motors that I have described.

If the field of a shunt motor is separately excited, as in the a. c. generator, and its armature served with a. c. the motor is called a *synchronous motor.* This motor when once started runs at exactly the same speed electrically as the generator in the power house which furnishes the power for it.

By that statement I mean that motor and generator armatures pass by the same number of pole pieces per second. Hence an 8 pole motor driven from a 6 pole generator would run at ¾ of the speed of the generator.

Series Motors Again.—If a series motor is served with a. c. all the polarities will reverse at the same instant. Since the rotative force is the same between a field and an armature pole as long as they are of unlike polarities, the motor operates equally well on d. c. and a. c.

The Universal Motor.—For this reason vacuum cleaner motors, and all those sold for use over widely spread areas are series wound motors. The owner of a vacuum cleaner can move from one city to another, from an a. c. district to some d. c. district and the series motor in the cleaner functions properly in both places.

Induction motors will be spoken of after the transformer has been explained.

Reversing a Motor.—The talk about a series motor on a. c. supply lines will show you that if the wires leading to any motor are interchanged at the point of supply, all you have done is to reverse all the polarities throughout the motor. This of course will not reverse the direction of rotation of a motor.

To reverse a motor reverse the connections of the armature or of the field but not of both.

Since weakening the field increases the speed, it is dangerous to open the field circuit of a motor while it is running. Do not arrange any switch that might open the field circuit at the wrong time and have all field connections tight.

Boosters.—When d. c. must be carried long distances the inevitable drop on the line may make the voltage at the distant place too low. Rather than raise the voltage at the power house we may *boost* it at the end of the line.

This is done by placing the armature of a series dynamo in the line and thus by its action adding a few volts of pressure. This can be driven by a motor

attached to the same supply lines that the booster is boosting.

Dynamotors.—By a clever method of winding the motor and dynamo coils may be on the same armature. Then one machine is a motor and a dynamo at once. These are called *motor-dynamos or dynamotors.*

These machines sometimes are attached to 110 volt lines and draw, say 100 amperes, but deliver 1000 amperes at 10 volts for use in the electro-refining of metals.

Rotary Converter.—When a dynamotor takes the supply for the motor from a. c. lines and delivers d. c. from its dynamo winding it is called a *rotary converter.* These must be used when the supply is a. c. and the work like electro-plating must be done by d. c., or any other place where d. c. is essential for operation and the current needed is large.

A Dissected Dynamo.—So that you may learn the names of the parts of a dynamo or motor, in Fig. 75 there is shown a d. c. dynamo taken apart. A d. c. motor or a universal motor would have exactly the same appearance.

Upon a shaft A is mounted a core on which the windings are placed. The part B is the part of the armature where the slots in the core are filled with the armature windings. This part passes before the pole faces N.

The commutator D is mounted far enough from B, that the ends of the windings may be bent around from slot to slot, and the ends of the coils formed by the windings may be brought to the commutator for soldering to its segments or bars.

The wires at C are not active in producing pressure. They are usually bound with tape and canvas to reduce friction as the armature revolves rapidly.

Bearings like E, with rings to carry oil up for their lubrication, are set in the pillow blocks F and F. The

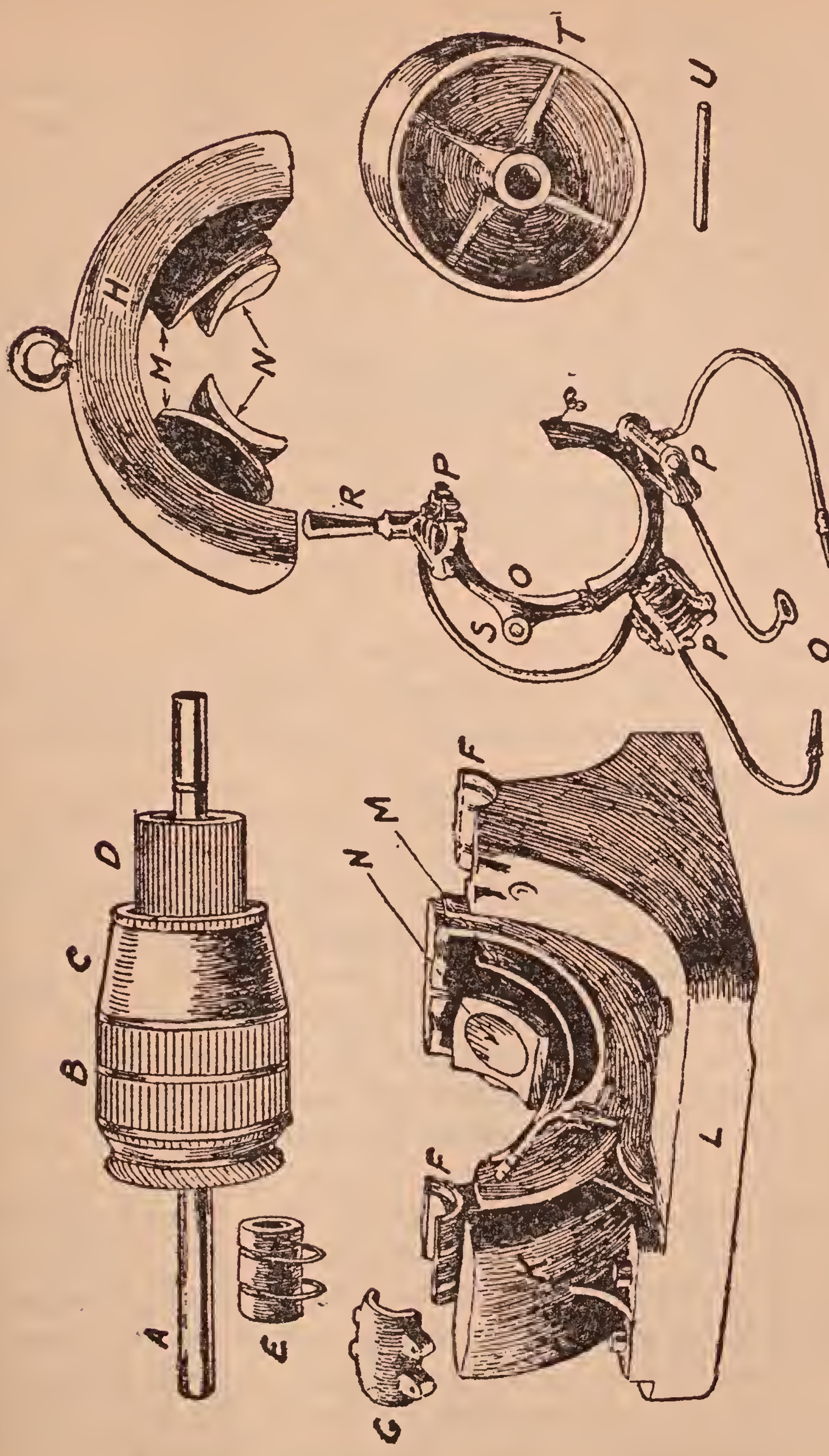

Fig. 75. The Parts of a Dynamo or Motor.

shaft A goes through the hole in the bearing E. The cap G holds the bearing E firmly in F.

The yoke or field ring H and K carry the field or magnet cores N. The field coils M when in place are held by the pole pieces screwed on N.

The lower part of the yoke K and the two pillow blocks are supported by the bed plate L.

The brush holders with their brushes P are held in a ring O so pivoted that the position of the brushes on the commutator can be adjusted. A bolt through S holds the ring O to the adjusting mechanism. R is the insulated handle by which the brush ring O is moved.

From the brush holders cables or heavy conductors Q lead to a terminal block or lug on the frame or yoke.

On the shaft a pully T is fixed by a wedge or as it is called a key U.

Putting these parts together in the factory is called the assembling of the dynamo. Putting it on its foundation in the power station is called the installing or setting up.

The Transformer.—When the voltage of an a. c. line is to be boosted or lowered, thanks to the principle of electromagnetic induction, it can be done by a device that does not contain mechanically moving parts.

We have learned that any motion of a wire across a flux or a flux across a wire produces current. That the e. m. f. of the current depends on the number of turns of wire and the strength of the flux. Let us review these facts by an experiment.

Experiment 45.—At one end of a bar of soft iron or a bundle of soft iron wires, about 5 inches long and ½ an inch in diameter, wind a coil of 20 turns of insulated wire. On the other end wind 10 turns of wire and do not cut the remainder of your wire off.

Arrange a set-up as shown by the hook-up of Fig. 76. A indicates a six volt storage battery or 3 dry

cells arranged in series. S is a pole-changing D. P. D. T. switch, details of which are given at the end of this chapter. B is the iron bar. P is the primary coil of 20 turns. S is the secondary coil of 10 turns. G is the galvanoscope. At one of the binding posts of the galvanoscope, scrape the insulation from the wire and loop the wire on the post. Do not cut off

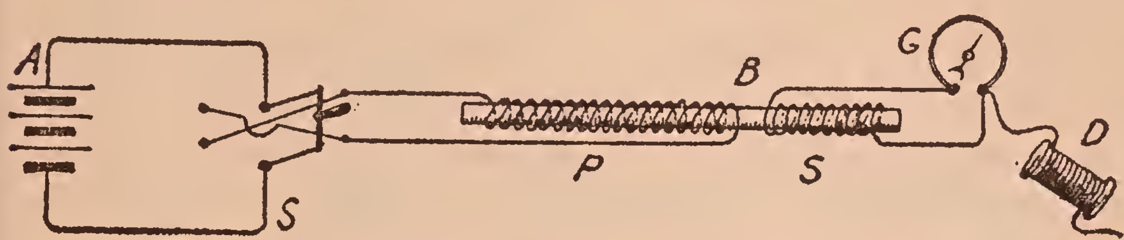

FIG. 76. PRINCIPLE OF THE TRANSFORMER.

the surplus wire but let it remain in a coil or spool at D.

The force that will act to deflect the galvanoscope will be a weak one, for you have a small amount of power at your disposal. Hence you must use the astatic needle magnet system in the galvanoscope.

Try the experiment just as described and when fully familiar with it, replace A with the cap G from the 110 volt control panel shown in Fig. 44. You may then get much a larger current in the primary P.

Throw the switch S to one side and notice the kick or momentary deflection of the galvanoscope. Throw the switch to the other side thus reversing the direction of the current and the kick of the galvanoscope will be in the opposite direction.

Thus by an alternating current you have through the magnetic flux of the bar produced an a. c. in the secondary coil.

Remove the wire from the binding post C and wind 10 turns more on the bar. Again scrape a little insulation and loop the wire under C.

Repeat the experiment obtaining larger deflections. Then wind on over the 20 turns, 20 more making 40

in all and repeat the experiment. The more turns on the secondary coil the larger the kick of the galvanoscope's pointer.

How a Transformer Works.—When two coils are wound on a soft iron core, thoroughly insulated from each other and from the core, you have a transformer.

Supply one coil with a. c. and the rise and fall in the strength of the flux will produce a. c. in the other. The one fed with a. c. is called the primary and the one in which the a. c. current is induced is called the secondary.

The power in the secondary is produced by the flux being moved across the wires of the secondary winding.

To calculate the voltage of the secondary, the primary voltage is multiplied by the quotient obtained by dividing the number of turns of wire in the secondary by the number of turns of wire in the primary.

The current in the secondary is obtained by multiplying the primary current by the primary voltage and by the efficiency expressed as a decimal, then divide by the secondary voltage.

SMALL TRANSFORMERS.—In Fig. 6 is shown a small transformer used to operate toys and miniature electrical railways. Small transformers like this but not adjustable for the voltage of the output are used as *bell ringing* transformers. These are connected to the 110 volt house supply and furnish 6 volts as an e. m. f. to operate the door and call bells of a building.

COMMERCIAL TRANSFORMERS.—In large cities these transformers are buried in brick chambers under the streets or in little vaults in the cellars of hotels and apartment houses. In the suburban districts they are to be seen on poles or up near the eaves of the buildings.

As pictured in Fig. 77 there are two wires carrying high voltage a. c. entering the transformer. The two wires leaving it are at a lower voltage but carrying

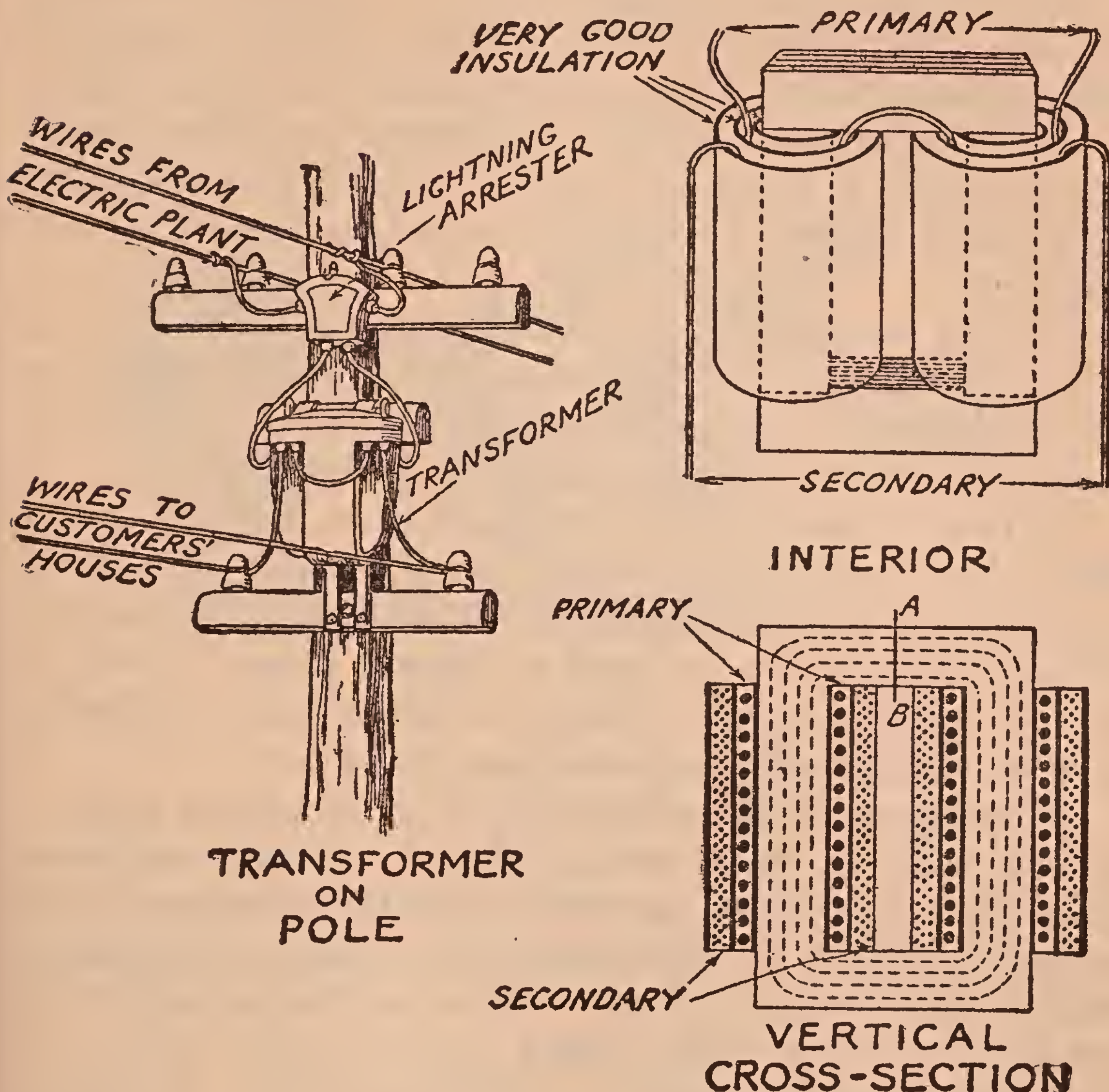

Fig. 77. The Commercial Transformer.

more amperes. This type is called a *step down* transformer.

The interior view shows the soft iron core and how the primary and secondary are each wound in two sections. The direction of the flow of the flux is shown in dotted lines.

If you will picture the actual magnetism as a something at right angles to these dotted lines and moving

around the magnetic circuit, then you will see that this magnetism would cut across the wires of the secondary winding.

Lay your pencil along the line A B and move it around back to its original position. If this was the flux it would be doing the things that we say flux does.

The Induction Motor.—Suppose a motor was almost ready to leave the factory. The brushes and the connection between field and armature were not yet installed.

Just as the machine stood it would be a sort of a transformer, with one part revolvable. Although there is no electrical connection to the armature there is a magnetic connection by means of the field flux.

If now we connect a polyphase a. c. supply to the field there will be generated in the armature, by a transformer action, a current. This current will cause the armature to revolve and we have a motor. Such a motor, when properly wound so as to run efficiently in this way, is called an induction motor.

Polyphase A. C.—Ordinary a. c. is single phase. When two or three single phase currents are sent through a set of two or three wires the combination is called two-phase or three-phase or simply poly-phase, which means many phase. This is "deep stuff," so let us leave it for another book.

Pole-changing Switch.—In Experiment 45 there was shown in a diagrammatic way a pole-changing switch which I would like to explain more in detail.

A switch of the D. P. D. T. type is wired as shown in Fig. 78 using insulated wires. The double-pole double-throw switch shown has convenient set screws. Should your switch have lugs the wires should be soldered into these lugs.

If this switch is closed by throwing the handle to the right, the current flows directly out and the wire C is positive while D is negative. Throwing the handle

to the left by means of the cross over wires makes C negative and D positive.

Go over the circuits in Fig. 78 carefully. The switch is shown almost closed, close it and the current from A flows to C, making C positive.

When the switch is thrown to the left, the current flows from A to E, then to D making D positive.

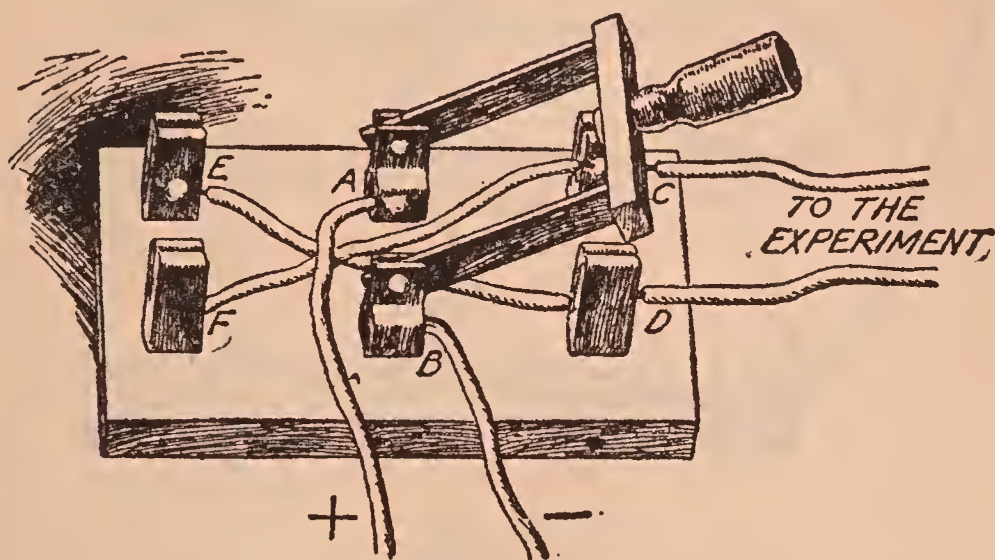

Fig. 78. A Pole-Changing Switch.

Commutating Switch.—I always liked to make things myself and so preferred another type of pole-changing switch. This latter type is usually called a commutating switch but is merely a pole changer.

In Fig. 79 you may follow the details as they are described. The base block is drilled half way through at four places and four binding posts A, B, C and D mounted near them. From each binding post an *iron* wire goes over to the hole which is filled with mercury. You must use iron wire, for otherwise the mercury would dissolve the end which dipped into it.

The jumper is made from heavy iron wires, or several twisted together and inserted in a small wooden block as shown at J and K.

The operation of this device reverses the polarity of the current going to the experiment.

Let the jumper board be so placed that J connects E and F and K connects H and G. Then D becomes the same polarity as A. If the jumper board is lifted, rotated a quarter of a circle and set down, then E

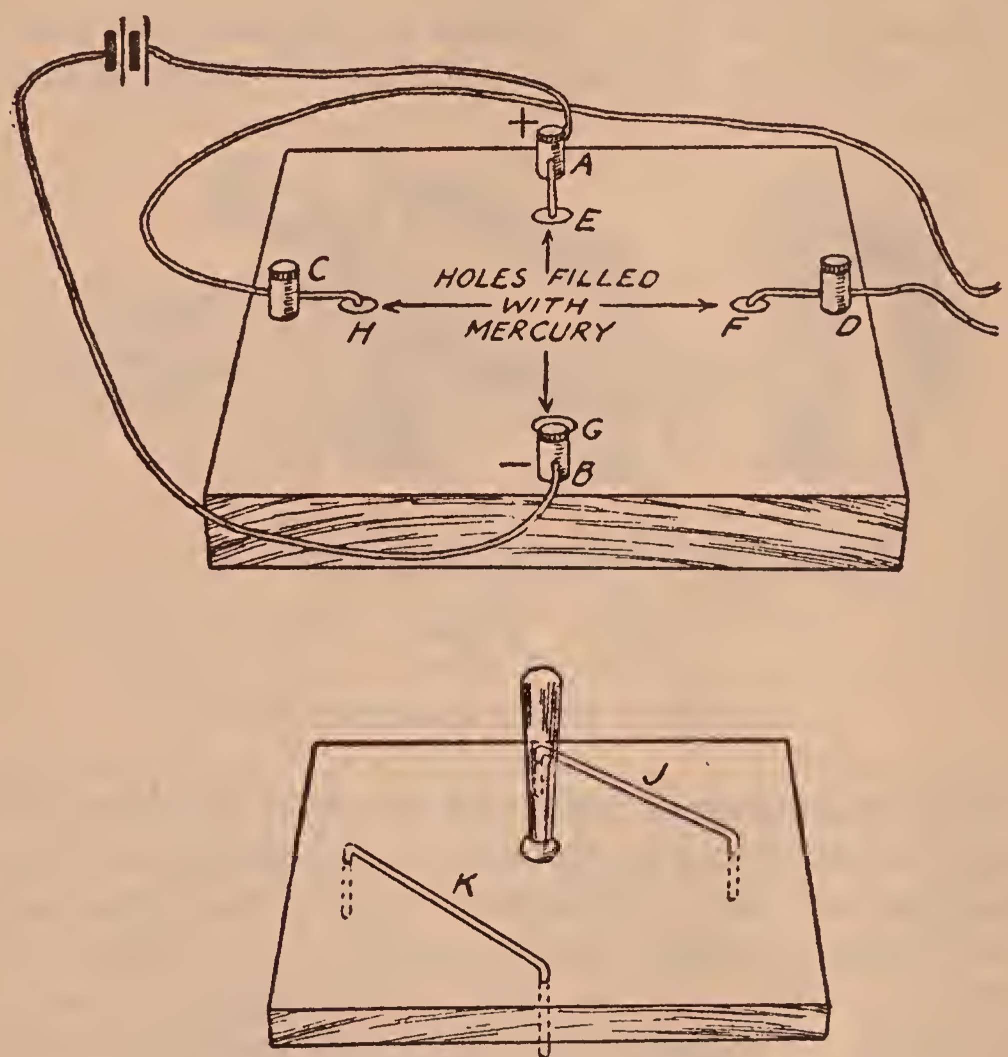

FIG. 79. A SIMPLE COMMUTATING SWITCH.

would be connected to H and G to F. This would make D the same polarity as B.

This simple device, easily made with your tools, is as good as the pole-changing switch the main part of which you would be compelled to purchase.

CHAPTER XI

FAMILIAR THINGS

THE ELECTRIC BELL
- The Push Button
- The Vibrator
- Bell Troubles

MULTIPLE CONTROL OF BELLS
- Group Control
- Two Way Communication

THE BUZZER TELEGRAPH

BUZZERS

SINGLE STROKE BELLS

THE RECORDING WATT HOUR METER

ELECTRIC LIGHTING
- Blackening of Bulbs
- Smashing Point
- Nitrogen Lamps
- Staircase Lighting

THE ELECTRIC IRON

THE ELECTRIC FAN
- Speed Regulation

STARTING A MOTOR
- Back E. M. F.

THE ELECTRIC ELEVATOR

ARMATURE RESISTANCE

STARTING BOXES
- Electrical Connections

THE TELEGRAPH
- The Key
- The Sounder
- The Circuit

THE TELEPHONE
- Sound
- The Transmitter
- The Receiver

HOW THE TELEPHONE WORKS

CHAPTER XI

FAMILIAR THINGS

The Electric Bell.—First we will consider the circuit which makes the operation of the bell possible. There is a cell ready to send out electrons from its negative terminal, which in a dry cell is the zinc can. The circuit must be complete at every point except the place from which we wish to ring the bell. At that place we insert a push button.

The Push Button.—As pictured in Fig. 80 the electrons go to a piece of brass at the top of the base of the push button. Above this is a flexible piece of brass which can be depressed by the button which projects through the cap. When these two make contact the circuit is completed, and the bell rings.

When one stops pressing on the button the spring action of the upper piece of brass lifts it out of contact with the lower one and the bell stops ringing.

The mechanism which keeps the bell ringing continuously as long as the push button is pressed on is simple, yet very ingenious.

The Vibrator.—The electrons entering the bell at B go on a wire to C. Here a post projecting from the frame of the bell supports a flat but bent spring, shown at E. This spring supports a bar of soft iron D which is called an armature.

When the electromagnet G is not magnetized the spring E draws the armature away from the magnet and presses the lower end of itself against a screw F. We can adjust the amount by which this screw projects from its support and lock this adjustment. There is a

lock nut for clamping the screw, so that vibrations will not move it.

The electrons travel along the spring E to the screw

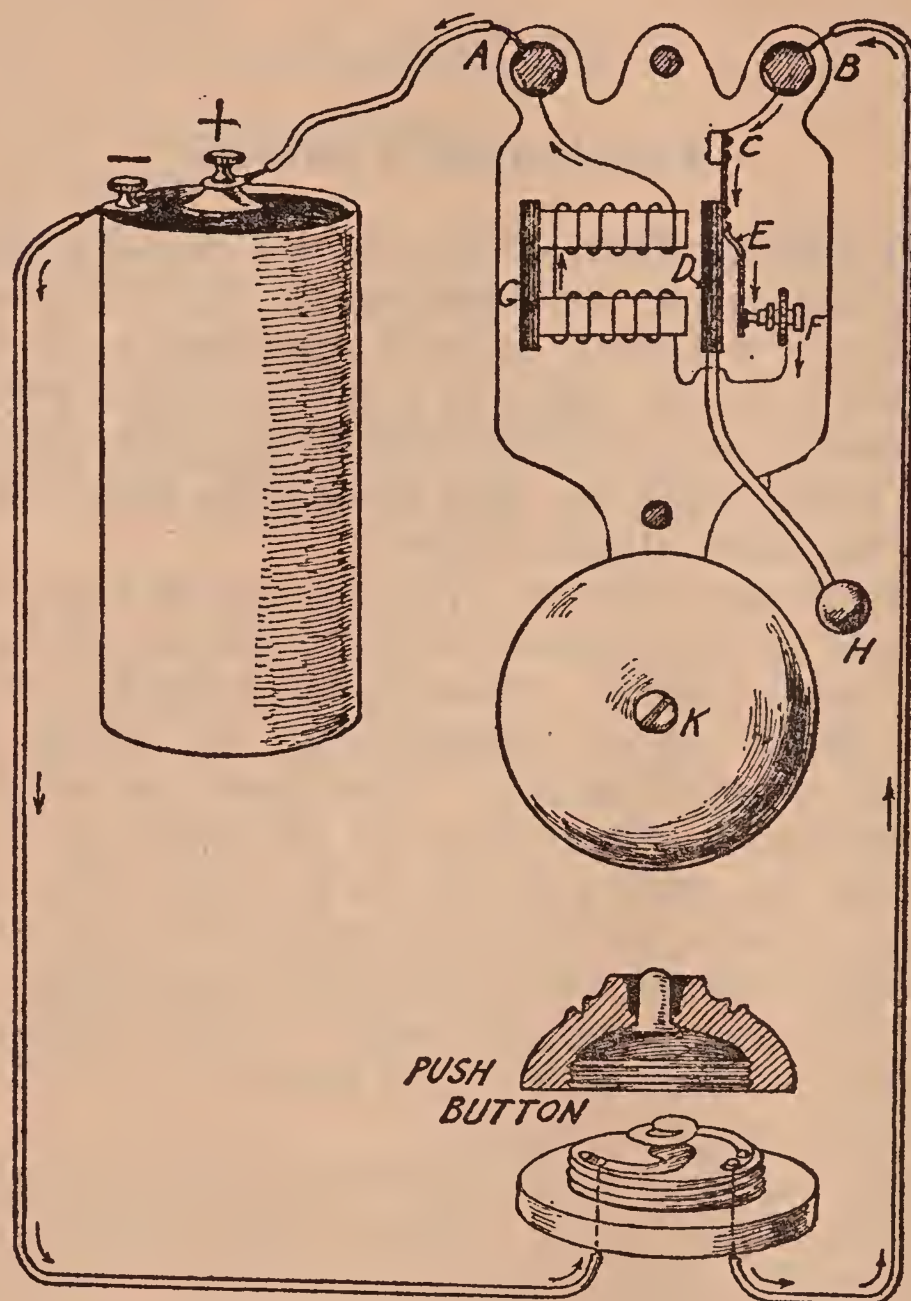

FIG. 80. THE ELECTRIC BELL.

F and thence along the winding of the electromagnet G, up to the binding post A and back to the cell.

Remember that I am talking about the flow of the electrons. Were I talking about current the arrow in Fig. 80 would point in the opposite direction.

Look carefully at Fig. 80 and you will see that where the circuit is completed G becomes a magnet and the armature D is attracted to the magnet making the attached hammer H hit the bell or gong K, so we hear a *ting*.

But as soon as the armature moves over far enough to ensure a stroke of the hammer on the gong, the spring E moves out of contact with the screw F. This breaks the circuit.

When the circuit is broken, G is no longer a magnet, for no electrons flow through its windings. Then the part of the spring near C pulls the armature away from the demagnetized cores of G.

This action brings the lower end of spring E again into contact with F, the magnet becomes energized. D is again attracted and again the bell rings a *ting*.

In fact the bell goes on merrily ting-a-linging as long as some one leans against the button of the push button.

This comes very near to being perfectly simple and simply perfect. All the troubles we have with bells seem to be due to cheap bells and once in a while due to a cheap push button. If the cell wears out, please do not say that the bell is out of order. If the wires are long and you have purchased a good bell, use two cells in series.

Bell Troubles.—When a bell ceases to ring, first look at the lock nut on the screw F. Should it be loose, adjust the screw F until the bell rings nicely and lock the nut tightly. Look for loose connections at all binding posts. Then go to the battery.

There is no convenient way of testing cells. They have a nasty way of keeping up appearances, showing a very commendable spirit, by giving full voltage, but yet not being able to send enough electrons to tickle the bell, much less make it ring.

Please do not laugh. The way to test cells is to

buy new ones and place them in service. If now the bell operates properly it proves that the old cells were no good. If you find the new cells do not make the bell work, then find the trouble and put the new cells in parallel with the old ones. You will get full service out of both sets of cells.

Two rows in parallel, each row containing two cells in series, which makes four cells in use, will give more than twice the hours of service than only two cells in

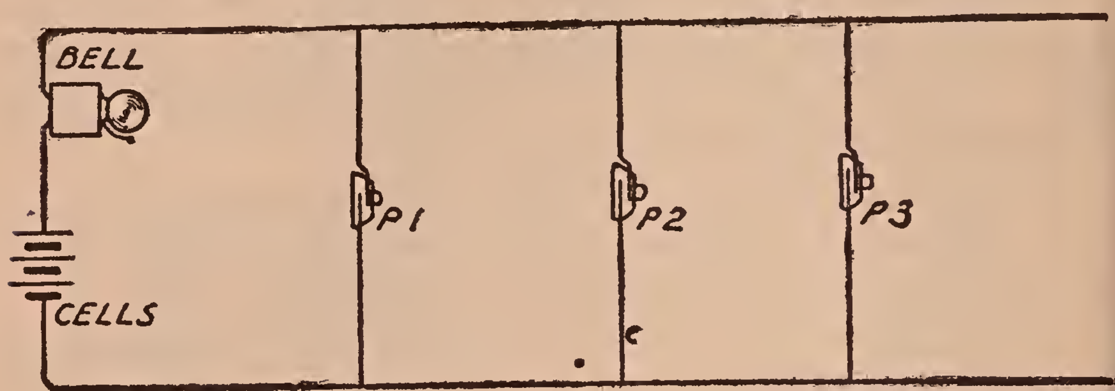

FIG. 81. MULTIPLE CONTROL OF A SINGLE BELL.

series. This is because in the parallel arrangement the cells work at a slower rate.

Multiple Control of Bells.—We often want to ring a single bell from many places. This is accomplished by wiring according to the diagram in Fig. 81. Any one of the push buttons will close a circuit causing the bell to ring. If two push buttons are operated at the same time the bell rings just the same. Notice that in this hook-up the bell and the cells are close together.

GROUP CONTROL.—When we want to ring bells at different places at the same time we arrange them as in Fig. 82. Notice that a push button and its battery of cells are close together. No current can flow to any bell from any set of cells in Fig. 82 until a push button is operated.

In connecting the cells to the circuit, be sure that

the carbon or positive terminal of each set is connected to the same bell wire. By bell wire I mean, wire leading to the group of bells. If you do not take this precaution, when two push buttons are operated at the

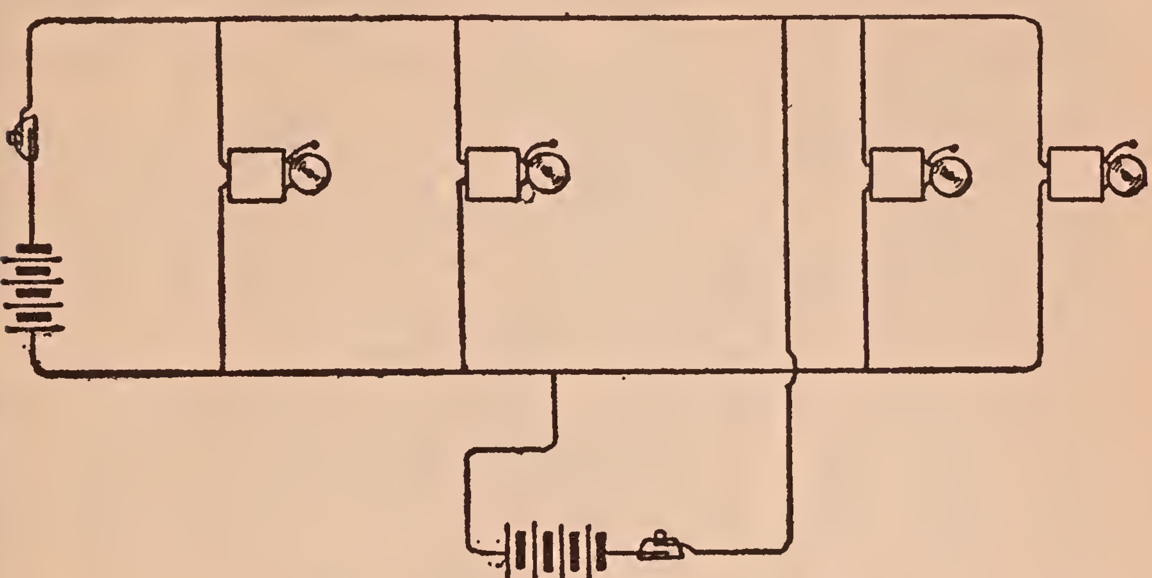

Fig. 82. Control of a Group of Bells.

same time, you might place equal and opposite voltages on the bell wires and so send no current to ring them.

Two Way Communication.—The wiring diagram in Fig. 83 provides a way for Sam to signal to Bill

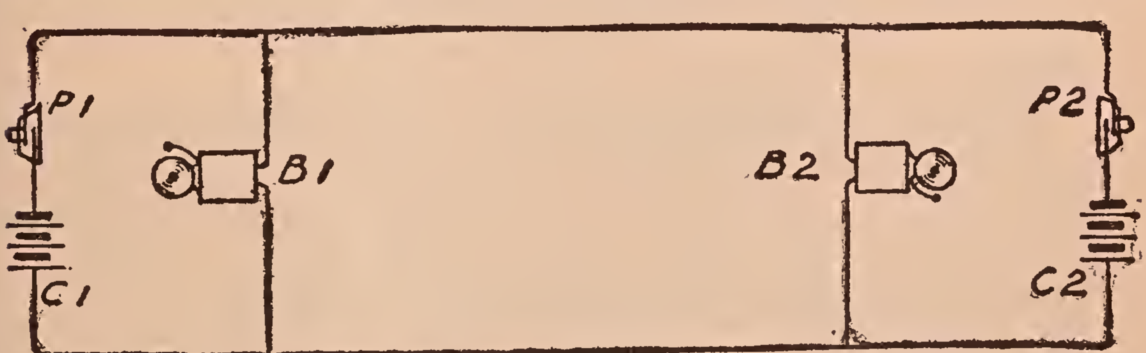

Fig. 83. Two Way Call Bell System.

and know that the bell in Bill's room probably rang. For when P1 is operated the cells C1 cause both bells B1 and B2 to ring.

Unfortunately it is possible for Bill to detach one wire from his bell B2. Then Sam can't ring the bell B2 yet Bill can ring up Sam.

This system provides for a two way communication. If you installed this system from mother's room to a maid's room, then when the maid heard the bell ring, she could at once signal back that she had heard and was coming. Also the ringing of the bell in mother's room would be an assurance that the system was in working order.

The Buzzer Telegraph.—If you replace the bells with buzzers, and the push buttons with keys, you could telegraph between two rooms or nearby houses. You would of course use the radio method of telegraphing by the lengths of the sounds.

This outfit is the best way for two fellows to study the radio code. You can dah-de-dit-dah as much as you please and not ruin the air for other listeners. F. b. o. m. When you become a radio *ham* you will know what that means.

Buzzers.—When you remove the gong and the hammer from an electric bell you have a device that buzzes. This peculiar noise makes a good call signal and yet is not so loud as a bell.

They are used wherever the signal will sound near the person wanted. Dad probably uses buzzers at the office.

Single Stroke Bells.—To ring a set of signals such as two for one person, and three to call some one else, with an ordinary bell is rather a noisy operation.

If the screw that touches the spring contact of an ordinary bell is turned up against the spring so as to make a permanent contact, we have a single stroke bell. This bell strikes its gong once every time a contact is made at the push button.

The Recording Watt-Hour Meter.—Near the point where the electric supply wires enter a building a meter is installed. This device must register how much power you use and for how long you use it.

It is a recording meter because it registers on a set

of dials the proper numbers to enable the Service Company to render the correct bill. Some meters, like galvanometers, ammeters and such instruments do not make a record as this meter does.

It is a watt meter because the watt is the unit by

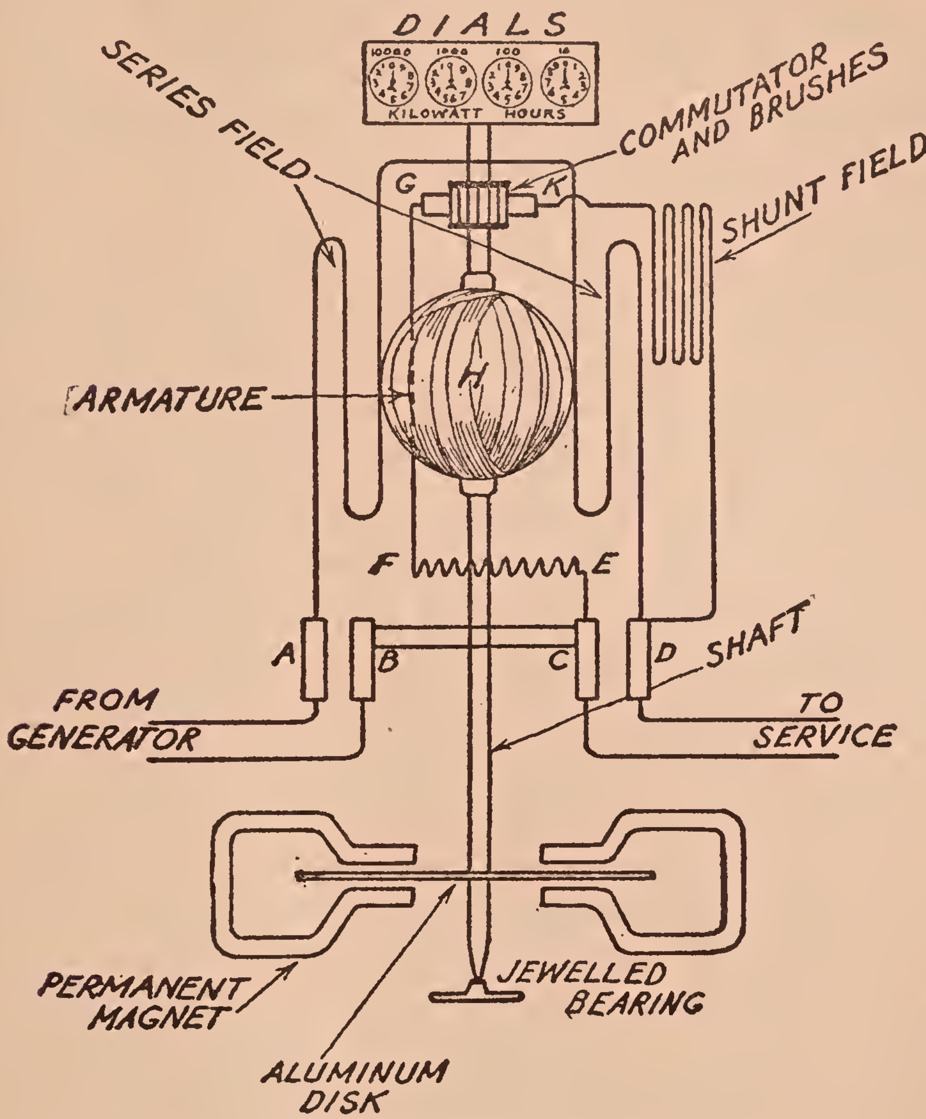

Fig. 84. A Kilowatt-Hour Meter.

which power is sold. This particular type registers in the larger unit of 1000 watts or a kilowatt.

It registers time because the longer the power is used, the longer the dials are turned and so the more the meter registers.

This meter is really a small motor. The interior arrangements are shown in Fig. 84.

The wires which enter the building are attached to the heavy binding posts A and B. From A the current flows through the two series field coils and thence through D to the service wires of the user. Every ampere of current that the consumer uses goes through this series field and increases the speed of the motor.

From B to C is a heavy copper strip, so that electrically they are the same. It is a convenience when connecting the wires to have two places for the *two* wires of the cable or B.X.

Starting from C there is a circuit passing through the armature of the motor. If you will follow it through the resistance E F up to the brush G, then through the armature H, out of the brush K, through a field and down to D, it shows that this entire circuit is a shunt on the main line. For this reason the field coil in this circuit is called the shunt field.

If the meter were changed from a 110 volt to a 220 volt circuit the resistance E F would be replaced by one of greater value. This would protect the armature from too great a current which would overheat it.

The shunt field is often called the starting coil for it is moved as close to the armature as possible without incurring the danger of starting the motor. Then when current flows the motor starts at once, for the friction is almost balanced by the starting coil.

When lamps, toasters, fans and such appliances are in operation the current drawn by these goes through the series field. We then have a motor which revolves the faster the more current you use.

To stop the meter promptly when the current is shut off, a magnetic drag is used. The permanent magnets act on the aluminum disk so as to form a dynamo, which like any dynamo resists being turned.

This drag does not increase the size of the bill you receive, because that is allowed for in the *calibration* of the meter. Calibration means adjusting the speed

so that it will correctly register the energy actually used.

The moving parts rest on a jewelled bearing to reduce friction.

The dials show the number of kilo-watt-hours of energy that have passed through the meter.

An Explanation.—I told you that shunt motors liked to run at a steady speed and that series motors were great workers at low speeds. The designer of the motor for this meter made it a series-shunt motor and so obtained the qualities, that made the change in speed proportional to the watts going through it. You will notice that in this motor the main field is in series with, and the armature is a shunt on the line.

Remember when I said that the increased field strength lowered the speed of a motor. So it does when there are iron cores in the field coils, and a very small air gap between field and armature. But in this motor where there is no iron core in the armature nor fields and where there is an enormous air gap between them in comparison to an ordinary motor, the action is different. Here increasing field strength means increasing speed.

Electric Lighting.—The only practical method of lighting the interior of a dwelling is by the use of *incandescent* lamps. This name means that the filament inside the lamp is heated to incandescence, which means white hot. The wire does not burn up nor oxidize for there is no oxygen in the glass bulb. It is exhausted to a vacuum and sealed, or after being exhausted is filled with nitrogen or argon gas and sealed.

The filament of a modern lamp is made of the metal tungsten, about three one thousandths of an inch in diameter. A long piece is strung in zigzag fashion on a glass support. The resistance of the filament is adapted to the 100 to 120 volt circuits on which the lamps are to be used.

The candle power of the lamp depends on the temperature, and the length of the filament.

All vacuum bulb lamps are operated at the same temperature and so the length of the filament must be designed to have a certain resistance. Thus the current drawn by the lamp is determined, the current heats the filament, and we get light.

Blackening of Bulbs.—Although the filament cannot burn or oxidize in the vacuum, it is heated so hot that it slowly boils. The metal slowly vaporizes and condenses on the inside of the glass bulb. Thus the bulb blackens and the light is weakened.

Smashing Point.—When a bulb has become darkened it is cheaper to take it out and smash it, than to continue to use it. For you either will find yourself using two lamps to get the proper illumination or injuring your eyes.

It costs less money to buy a new lamp than to run two darkened lamps.

Nitrogen Lamps.—If the bulb after the vacuum is formed is filled with a gas which will not oxidize the filament nor permit it to burn up, we find evaporation of the tungsten filament is very much retarded.

This lamp may be designed to operate at a higher temperature. This makes the lamp give more light for less current used, which means for less money. A vacuum lamp requires 1¼ watts to furnish 1 candle power of light. A gas-filled lamp will produce the same light consuming only 0.8 watts.

Staircase Lighting.—There are many places where two lamps or two groups of lamps ought to be independently controlled from two places. Staircase lamps fall in this class, when duplex control is needed. Such a system of control is shown in Fig. 85.

The lamp A is at the head of a stairs and lamp B at the foot. Switch A is upstairs and switch B downstairs. These switches are of the familiar type where

two buttons project in turn through a brass plate, and pushing the protruding button accomplishes the desired result. Yet they differ from the regular switches in

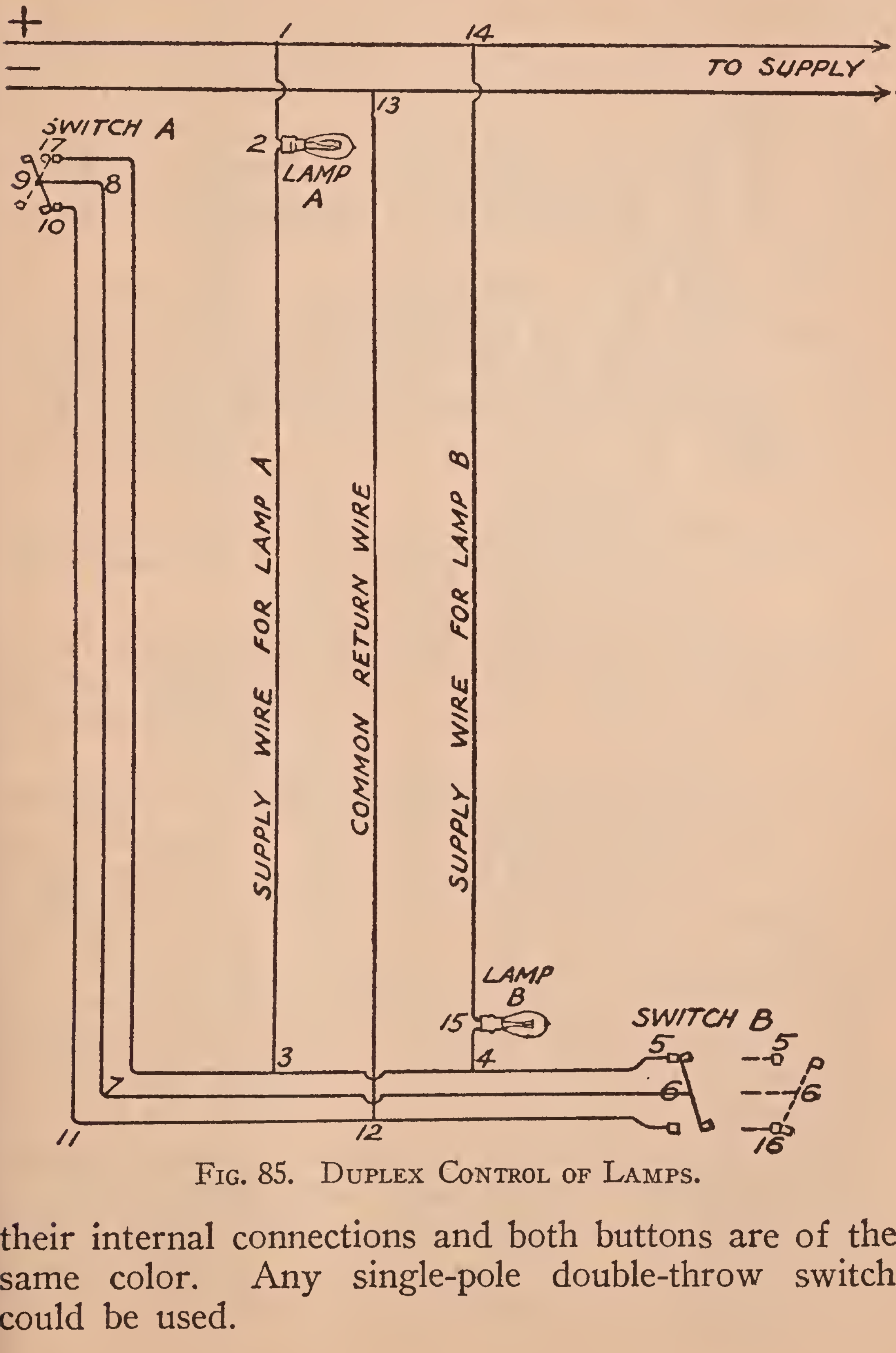

Fig. 85. Duplex Control of Lamps.

their internal connections and both buttons are of the same color. Any single-pole double-throw switch could be used.

You could make a model of a system like this using flashlight lamps and dry cells. Then you could demonstrate to your friends exactly how such a system operates.

As the switches are set in the diagram both lamps are lighted. To convince yourself of this, start at the supply lines at the point marked 1 and follow the circuit through the points as numbered in order. When you get to 13 you have completed the circuit that feeds lamp A.

If you start at 14, then to 15, to 4 and then consecutively to 13 you get the circuit feeding the lamp B.

Suppose you had just come downstairs and wished to turn off both lights. Pushing the projecting button of switch B would open the circuit of both lamps at point 5.

If you wish to ascend the stairs again, then push the switch back to its original position, and the lamp will light.

Should you not do this but leave the switch B as shown in the dotted position, with the lights extinguished, the system is ready for some one else to descend.

Let them, at the head of the stairs, push switch A over to the dotted position and both lamps will be lighted. The circuit for lamp A will now be through the points 1, 2, 3, 17, 9, 8, 7, 6, 16, 12, 13 and similarly for lamp B.

Thus the lamps can be controlled at two places.

The Electric Iron.—This is such a convenient appliance that it is probably the first electrical device purchased by a family.

What you want in an iron is heat. Since the heat produced depends on the watts converted from electrical energy into heat, you must purchase watts. The voltage of your supply being a fixed quantity, to get more watts you draw more amperes.

These amperes flowing through resistance cause heat in proportion to the square of the amperes and to the ohms of resistance. Increasing the current from 1 to 2 amperes would increase the heat to 4 times its former quantity. Nearly all irons draw about 5 amperes from

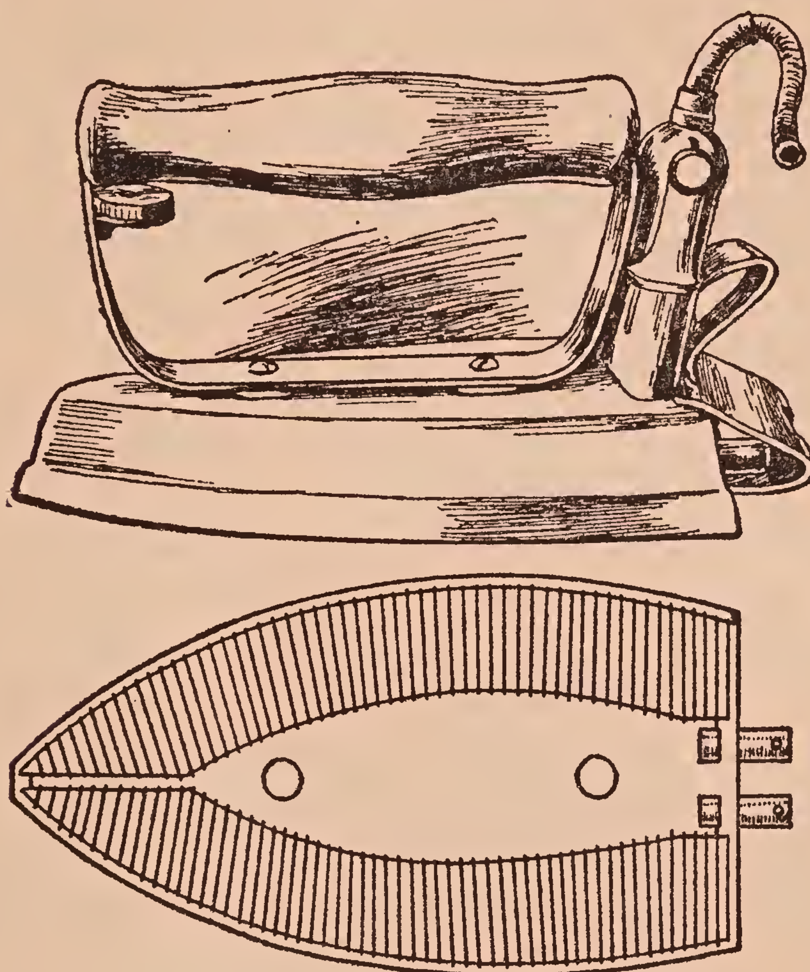

FIG. 86. THE ELECTRIC IRON.

the line, use power at the rate of 550 watts and cost from 10 to 20 cents the hour to use depending on the cost of power.

The heating element of high resistance wire is shown in Fig. 86. This wire is wound on asbestos board and then mounted in the lower part of the iron.

To disconnect the iron a removable plug is used. Where the flexible cord containing the supply wires enters this plug the bending is severe, and this is where the wires break.

The Electric Fan.—Perhaps I should say at once that we are going to discuss the motor in an electrically driven fan.

The small desk fan and the wall fan of the size used in homes and business offices is driven by a series motor. This fan may be used on d. c. or a. c. systems.

Speed Regulation.—There are several ways of regulating the speed of a motor. One is by placing more and more resistance in the circuit which reduces the pressure available to run the motor, and thus reduces the speed. Another way is to weaken the field by shunting turns of wire in the field winding and so increasing the speed.

Starting a Motor.—When you wish to start a fan you push a button or snap a switch and give the matter no further thought.

The resistance of the motor is sufficient to prevent a very large current from flowing. But should you hold the blades from revolving by a piece of wood and then turn the switch, the armature would grow hot and soon the insulation would be burnt.

We know that this does not happen when the fan is going and so we suspect that a rotating armature draws less current from the line than a stationary one. An ammeter in the line with the armature under these two conditions shows a great difference in the currents. Please do not try this for you will surely ruin an armature.

What is it that chokes the current back when the armature is revolving? It is the e. m. f. that the motor generates as it revolves. This e. m. f. is against the voltage of the line and hence reduces the actual number of volts sending amperes through the motor.

Back E. M F.—We call this voltage which the motor prōduces a back or counter e. m. f. When you realize that in a revolving motor we have all the elements of a dynamo you will understand why this back

e. m. f. is generated. In the motor in motion there are wires on the armature cutting the flux from the fields. If you cared to apply the rules of direction of flux, motion and induced current; and also the rules of the magnetic thrust on a wire in a flux, you would be convinced that: The voltage generated by the dynamo action of a motor is less than and in the opposite direction to the voltage which makes that motor run.

It is the difference between the line voltage and the back e. m. f. which forces current through the armature. As the load on a motor increases its speed slackens. This makes the back e. m. f. lower, which in turn increases the difference between the line voltage and the back e. m. f. Thus a larger voltage is applied to the armature and more current flows to produce the power to move the load.

In this way the current taken by a motor is automatically regulated to be just enough to do the work demanded of it.

The Electric Elevator.—The elevator man moves a handle, and the elevator moves away from the floor like magic. You know in a general way that there is a motor down in the cellar but not perhaps much of how it starts and stops.

Armature Resistance.—The resistance of the armature of a 10 H. P. motor such as is used in a decent elevator service must be very low else the power wasted in the armature would be too great.

The armature of such a motor may be one thousandth of the resistance of a fan motor. If the voltage of the line were applied to the armature of this large motor, before it could get up enough speed to generate enough back e. m. f. to protect itself, the armature would have been badly damaged from the heat due to the large current flowing.

Starting Boxes.—In order not to "burn out"

armatures with the heat from the first rush of current, a starting resistance is put in the circuit at first, and is cut out a little at a time as the motor gains speed.

As this simple starting resistance is accompanied by other devices the whole thing is usually called a starting box.

In its simplest form this consists of a lever whose first movement completes the field circuit. Then the motor cannot run at an excessive speed or *race*. For if the motor tries to go too fast the back e. m. f. will become so great that it will not permit enough current to flow to run the motor Thus the excessive speed commits suicide.

What I have just written applies to a shunt motor more than a series motor, so all elevator motors have a shunt field winding for the special purpose of holding the speed down to normal.

When the lever completes the field circuit, the next movement completes the armature circuit through a resistance. Further movement of the lever cuts out the resistance until full line voltage is on the motor.

The elevator man by the handle in the car closes a circuit which starts a little motor like a fan motor. This by a gear moves the lever of the starting box slowly over the contacts on the face of the box. Fig. 87 shows a starting box.

No Voltage Release.—If there should be a momentary interruption of the voltage the motor would stop and the return of the voltage would find an unprotected motor. It is true that some one ought to turn the starting box lever back to the safe starting point, but people forget things.

Therefore there is an automatic device which resets the starting box to a safe position whenever the line voltage fails. This device is a spring which would throw the lever back to safety unless held in a position to run the motor by some force.

As long as the motor is running the back e. m. f. of the motor magnetizes the *release magnet* which holds the lever against the action of the spring. Should the line voltage fail and the motor begin to slow down, very soon the back e. m. f. becomes so weak that the release magnet cannot hold the lever. Then the spring throws the lever back to the safe position.

OVERLOAD RELEASE.—If the no-voltage release coil was short circuited, or if a jumper or shunt were connected to it, it would be robbed of its current and hence of its magnetism.

An overload release is a magnet with its windings in the armature circuit. When by reason of an overload on the motor the current grows beyond a safe value, then the magnetism of this overload release becomes strong enough to lift a bar of soft iron. This, by some contrivance, short circuits the no voltage release, which losing its magnetism lets go of the lever and the spring moves it back to safety. Fig. 87 shows a method of doing this.

TO STOP LARGE MOTORS.—Any motor provided with a starting box should be stopped by opening the main switch. The starting box is not a stopping box. Opening the switch in the supply line to the motor cuts off the current, the motor slows down and when its back e. m. f. becomes weak the no-voltage release lets go of the lever and the spring resets the box for a new start.

ELECTRICAL CONNECTIONS.—In Fig. 87 is shown a starting box and how it is connected to the line and to the motor.

The box has three binding posts marked L A and F or with the words Line, Armature and Field. From the main switch one wire goes to the L post on the starting box and the other wire is connected to the post marked L on the motor.

The lever on the box is connected to the "line" bind-

ing post. The first movement connects the line to the strip making the field connection. A further movement completes the circuit through the whole starting resistance to the armature.

In the field circuit there is the magnet which is magnetized as long as the line voltage is on the motor and also as long as the back e. m. f. of the motor is strong

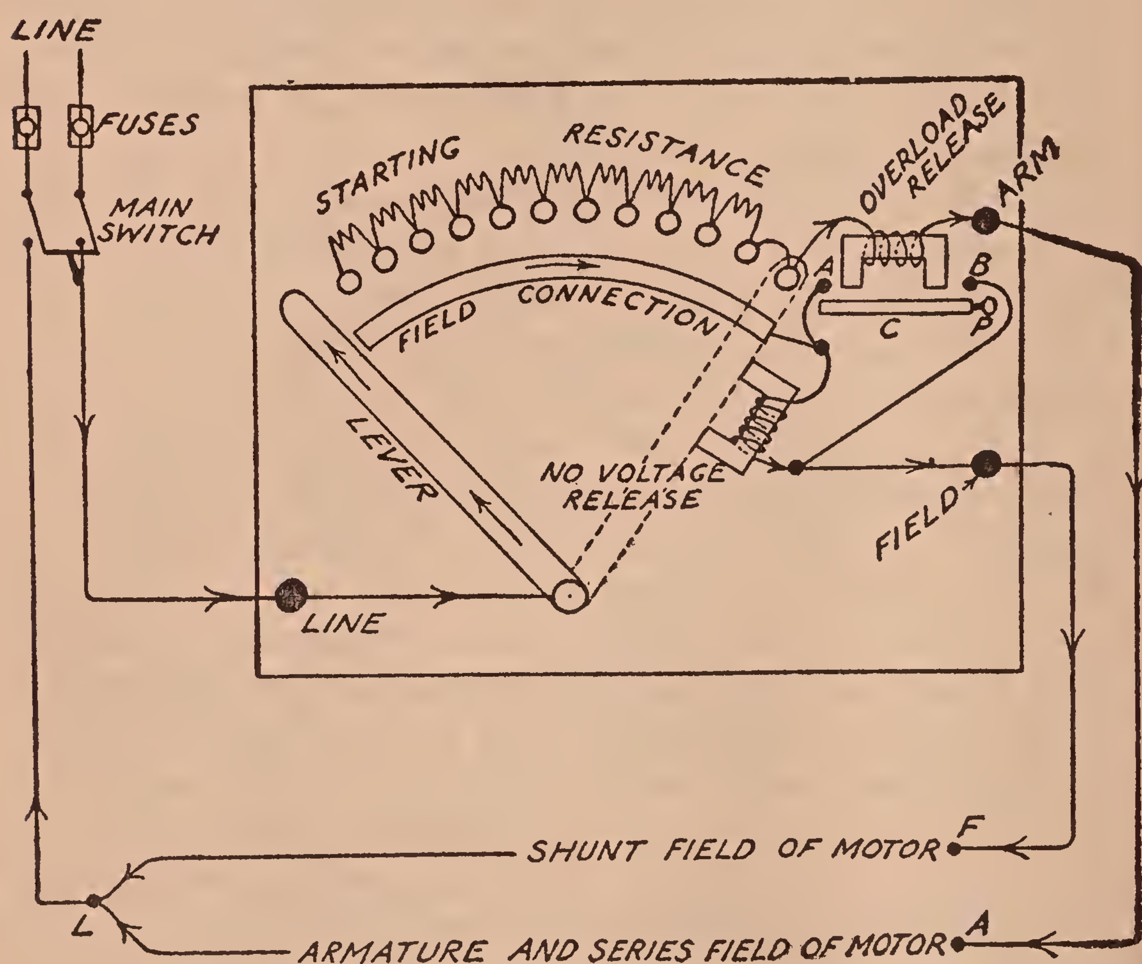

FIG. 87. A STARTING BOX.

enough to protect the motor from a dangerous flow of current.

If the posts A and B were connected the no-voltage release magnet would be short circuited and lose its magnetism. As the current flows to the armature through the overload release magnet, should that current become too large, the magnet becomes very strong. Thus the iron lever C, which is pivoted at P, is pulled

up against the posts A and B. This kills the magnetism of the no-voltage release and the motor is stopped as explained before.

The terminals on a motor with a shunt field are either marked F, A and L or one can easily trace the connections. The post marked L is a common return for the armature and shunt field currents and is connected directly to the supply line.

In Conclusion.—Fan motors and those used for sewing machines, cleaners, coffee grinders and where small quantities of power are needed will be found to be series motors with commutators. These run equally well on a. c. or d. c.

The Telegraph.—Until radio grew so popular many boys had their own private telegraph lines between their homes and those of their friends. The code could be learned and then there was lots of fun "pounding brass" back and forth.

Radio "hams" use the International Code which differs slightly from Morse. Land telegraphy is a series of short and long silences separated by clicks of noise, while radio telegraphy consists of short or long buzzes separated by gaps of silence.

Today a live wire boy will build a buzzer line as described on page 248. Then he will learn to send in code and to read code. Thus he will get more fun out of a radio receiver.

There are plenty of telegraphs used on land wires today and there always will be. Radio has taught us how to make a land wire carry four telephone conversations and six telegraph messages at the same time, but it has not nor will not displace land wire telegraphy.

The hook-up of a simple telegraph circuit is shown in Fig. 88.

The Key.—The key is a switch designed for ease and rapidity of operation.

The standard key moves up and down. There is a

special key for high speed work, which has a sidewise motion. It is constructed so that when the lever is swung to the right the key automatically sends dots as long as it is held there. With this key the operator can send at a high speed with the least possible fatigue.

The Sounder.—A horseshoe electromagnet is intermittently energized by the action of the key. This causes a lever to strike on the metal frame and make a click. When the lever is released a spring brings the

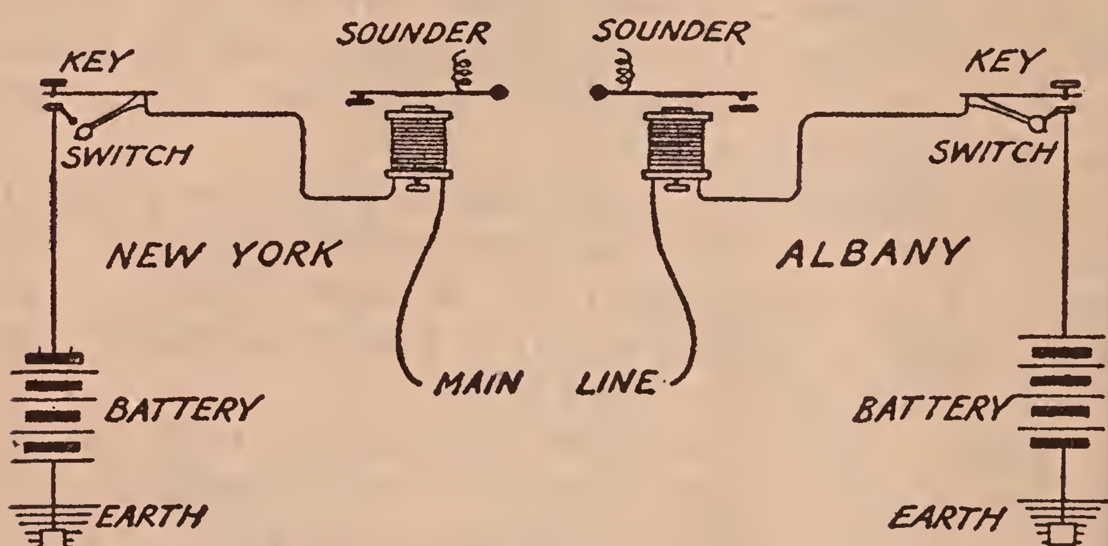

Fig. 88. A Telegraph Circuit.

lever against another part of the frame with another click.

The Circuit.—As shown in Fig. 88 a switch must be used at the "listening" end to bridge the gap caused by the key. Since both sounders operate when the man at New York sends, he may be interrupted by the Albany operator, who by opening his switch will cause both sounders to stop.

Today the ground is not used as part of a telegraph circuit. The resistance of the ground is so great that the expense of a complete circuit of copper is justified by the savings in operation.

The Telephone.—With two sets, each consisting of a transmitter, receiver, battery and transformer, and

following the hook-up of Fig. 89 you could set up a telephone system. For a call bell you would run a separate pair of wires with battery, bells and push buttons as shown in Fig. 83.

Before we dig into the parts of this system to see just how they operate, let us get a clear idea of what you do to the transmitter, when you speak into it.

SOUND.—Your lungs force air through the stretched vocal cords which vibrate so as to make the air come from your lips in puffs. These puffs of air follow each other at such close intervals that from 60 to 1,000

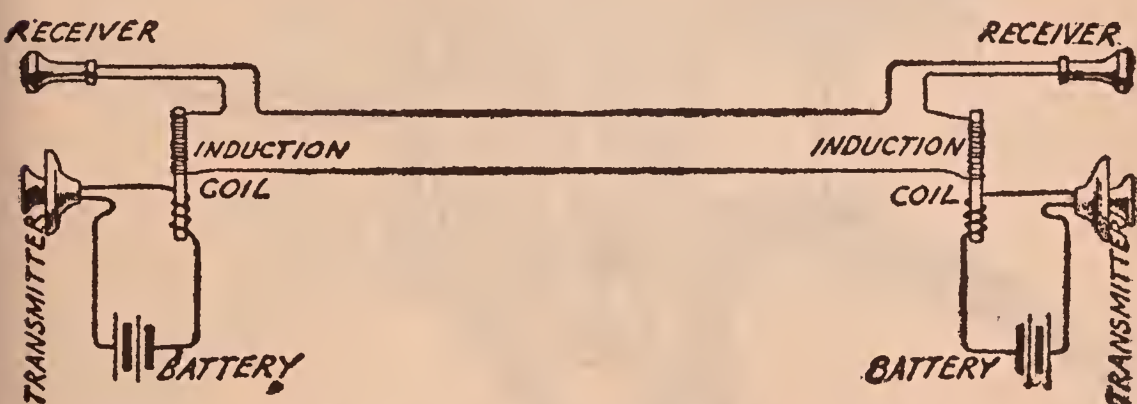

FIG. 89. HOOK-UP OF A SIMPLE TELEPHONE CIRCUIT.

of them occur in one second. Gentle as these puffs of air are, and rapidly as they follow each other, the flexible diaphragm moves each time a puff strikes it. The elasticity of the diaphragm, for it is a thin disk of elastic material, brings it back again, between the puffs of air.

We must make the diaphragm of the other fellow's receiver, make the same vibrations as the diaphragm of our transmitter. When this is accomplished, his receiver will vibrate, sending into the air a series of puffs, which his ear translates into sound.

THE TRANSMITTER.—You speak, as shown in Fig. 90, into a mouth piece and through the holes in the guard against the diaphragm D. A screw fastens this to a frame holding a carbon plate C. There is a second

carbon plate separated from the first by a ring of insulating material I. Thus a box is formed which is filled with carbon granules, G.

The vibrations of the diaphragm alternately squeeze the carbon granules into better contact, thus lowering

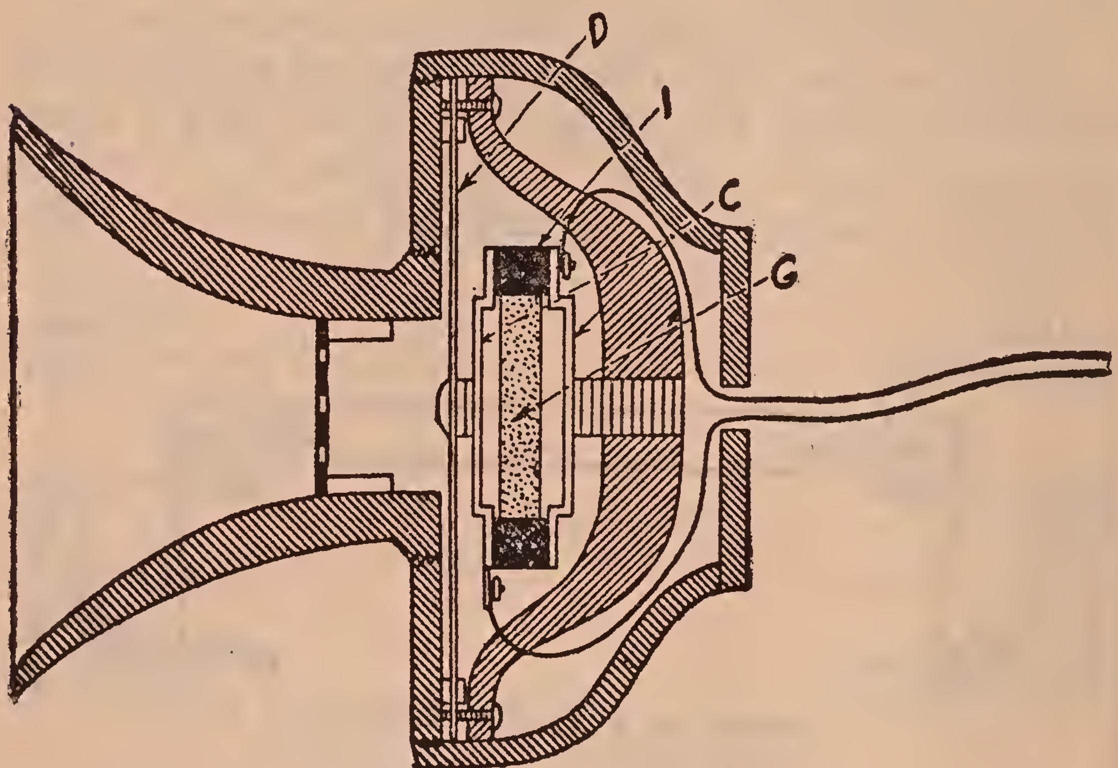

FIG. 90. A TELEPHONE TRANSMITTER.

their resistance to current, and then relax the pressure so that the resistance becomes high.

Looking back at Fig. 89 you will see that this voice-controlled resistance varies the current from the battery, and that this variable d. c. flows through the primary of a transformer. There is generated in the secondary winding of this transformer an a. c. of much higher pressure, which flowing along the line, affects the receivers.

THE RECEIVER.—As shown in Fig. 91, a very strong permanent magnet of horseshoe shape M is supported by a frame F. On each pole of the magnet is placed a coil of many turns of wire A. Size No. 28 is used

so as to get many turns in the small space available for the coils. The wires are soldered to two binding posts B, from which the larger telephone cord leads out through the hole H. Two wires are concealed in this cord.

The electrical parts of the receiver are contained in a hard rubber casing R which fits up behind the frame F, and a hard rubber cap C, which when screwed down firmly, holds the diaphragm D and frame F, securely

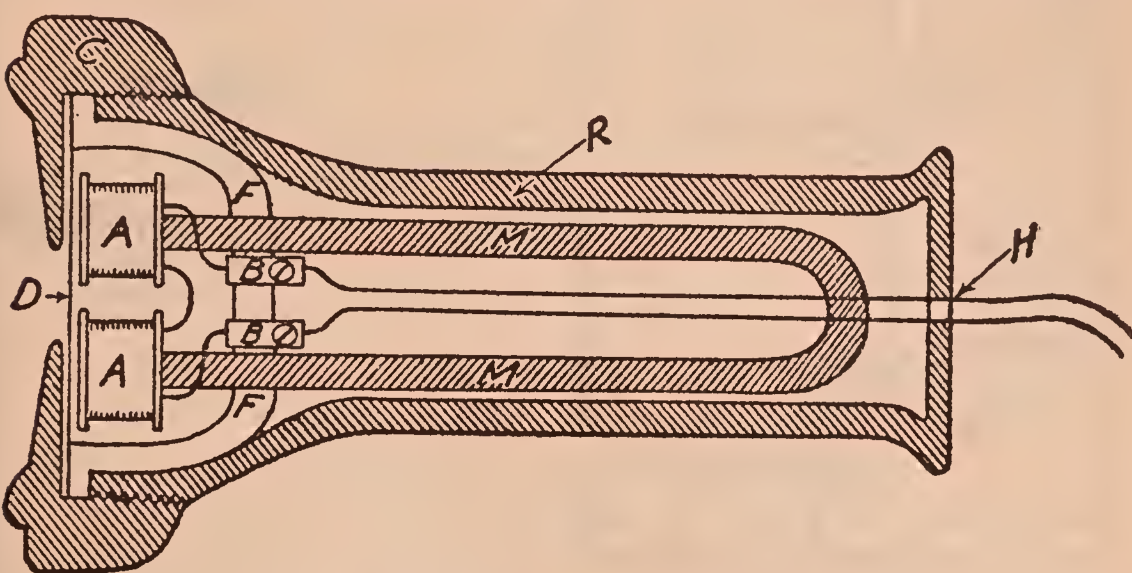

Fig. 91. A Telephone Receiver.

against the back casing R. The binding posts are insulated from, but supported by, the frame F.

The diaphragm D is thin, flexible and of soft iron so as to be magnetizable. It is very close to, but not touching the poles of the magnet.

We have a voice-controlled a. c. on the line, which passing through the coils A, alternately reinforces and diminishes the strength of the magnet M. Thus the diaphragm M is drawn forward and released, so that it moves precisely as the diaphragm in the transmitter does. Little puffs of air are then produced by this diaphragm, which correspond exactly to the little puffs that you made at your transmitter. Hence the listener hears sound.

The coils A are designed to make as great a change as possible in the magnetism of the magnet, but also to offer as little resistance as they possibly can to the current. These qualities are antagonistic, for coils of great magnetic strength when served with small currents, must contain lots of wire, which makes high resistance. An ordinary telephone receiver offers about 80 ohms resistance.

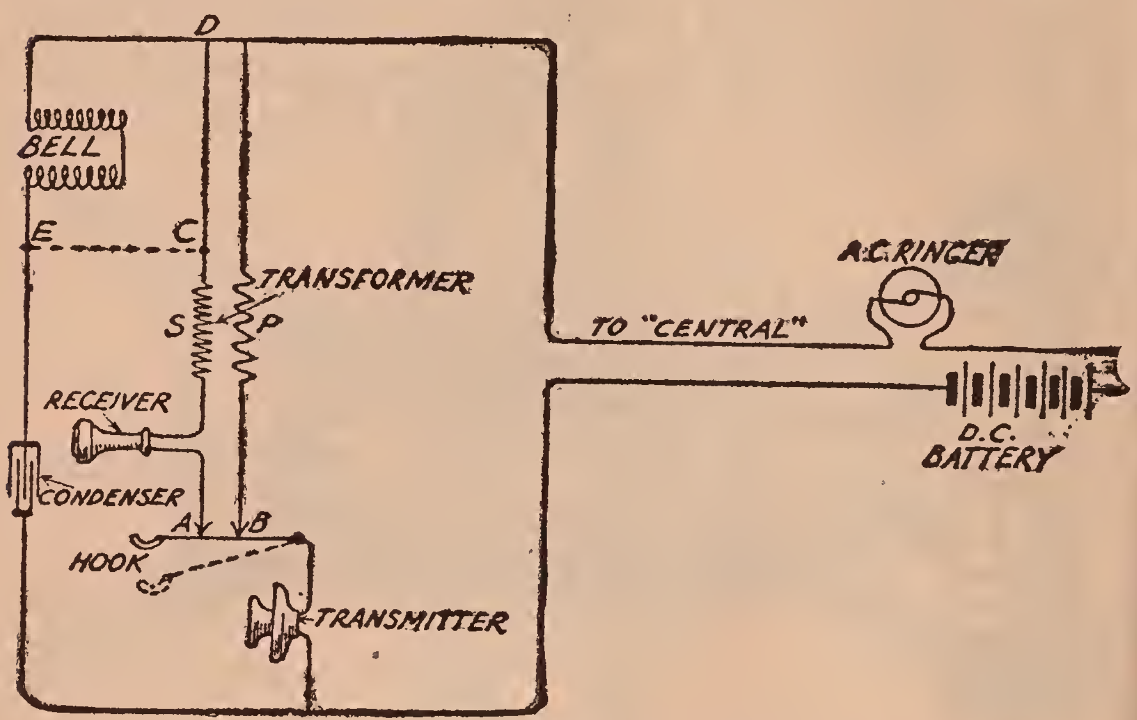

Fig. 92. Hook-up of a Telephone Circuit.

These receivers are not used for radio reception, the reason for which will be explained later on.

How the Telephone Works.—On the desk or table stands a telephone. The transmitter is supported on a stand and from the hook on the stand hangs the receiver.

In a box nearby is a bell, a condenser and a transformer. Fig. 92 shows a wiring diagram which explains how this telephone outfit operates.

The telephone stands there with the weight of the receiver holding the hook down, and so the two con-

tacts at A and B are not made. The d. c. from the "talking battery" at the central station cannot flow through the bell either, for the condenser is an open circuit for d. c., its insulation stopping the current.

Some one wants you. The operator connects the a. c. ringing dynamo to the circuit. Although your circuit is open at the hook switch points A and B, yet an a. c. current will pass its effects through a condenser. In this way an alternating current flows through the condenser and bell ringing it.

You pick up the receiver and the hook switch rises making contact at A and B. The d. c. now flows through your transmitter and primary P of the transformer. You then talk and altering the strength of the d. c. current, produce an a. c. current in the secondary. This current flows out on the line to the other fellow's receiver. When he talks to you, the a. c. from his end comes through your secondary S and operates your receiver.

If the parts of the telephone set were wired exactly as shown in Fig. 92 there would be several "troubles." The bell and condenser would act as a shunt for the a. c. talking current, thus weakening the current sent to the other end of the line. Also the primary of the transformer would act as a shunt on the secondary.

The telephone engineers avoid these "troubles" by omitting the wire from C to D and inserting a wire from C to E. This change in the connections also prevents too large a d. c. flowing through the receiver. For it places the bell whose resistance is 1000 ohms in series with the circuit that would carry d. c. to the receiver. This effectually blocks the 24 volt d. c. battery from sending much current through the receiver.

A desk set is shown in Fig. 93. In the cord from the box on the base board up to the telephone on your desk are three wires. Where they go and how they are connected is clearly shown in the picture.

The Induction Coil.—In a transformer the primary is served with a. c. and so the secondary furnishes a. c. An induction coil is a kind of transformer

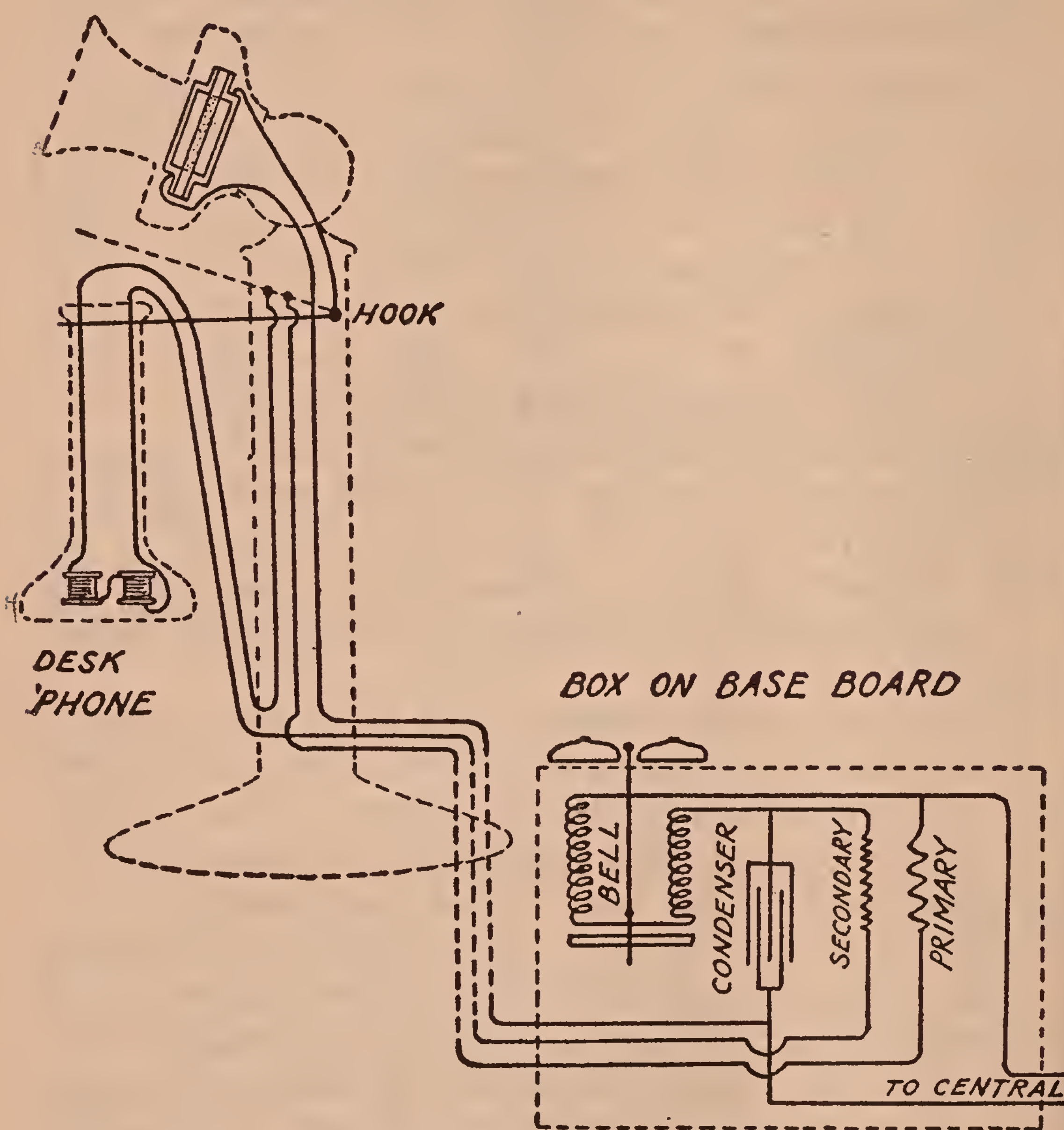

Fig. 93. Hook-up of a Desk Set.

to which we serve interrupted d. c. and obtain a. c. To obtain a clear idea of its action try this experiment.

Its Action.—*Experiment* 46.—Following the hook-up given in Fig. 94, we will connect a simple transformer to a source of current and to a galvanoscope.

The secondary is to have twice as many turns as the primary. The core must be very soft iron, annealed iron wires making the best material for the core.

Close the switch and observe the direction in which the galvanoscope moves. Notice that after its kick or

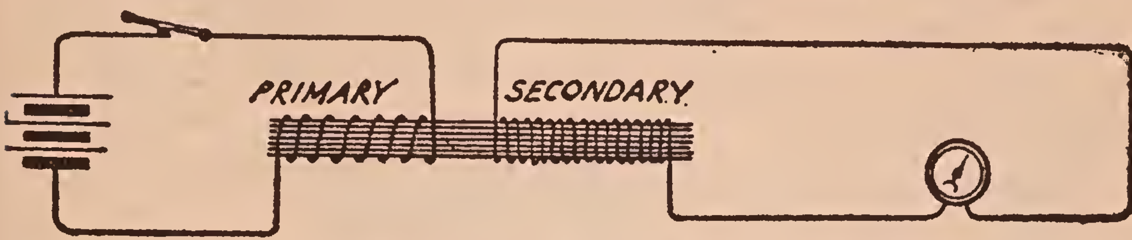

FIG. 94. PRINCIPLE OF THE INDUCTION COIL.

momentary deflection the needle returns to a position which indicates that no current is flowing. Open the switch and note that the kick of the needle is in the opposite direction.

Thus an interrupted d. c. in the primary of a transformer will induce an a. c. in the secondary.

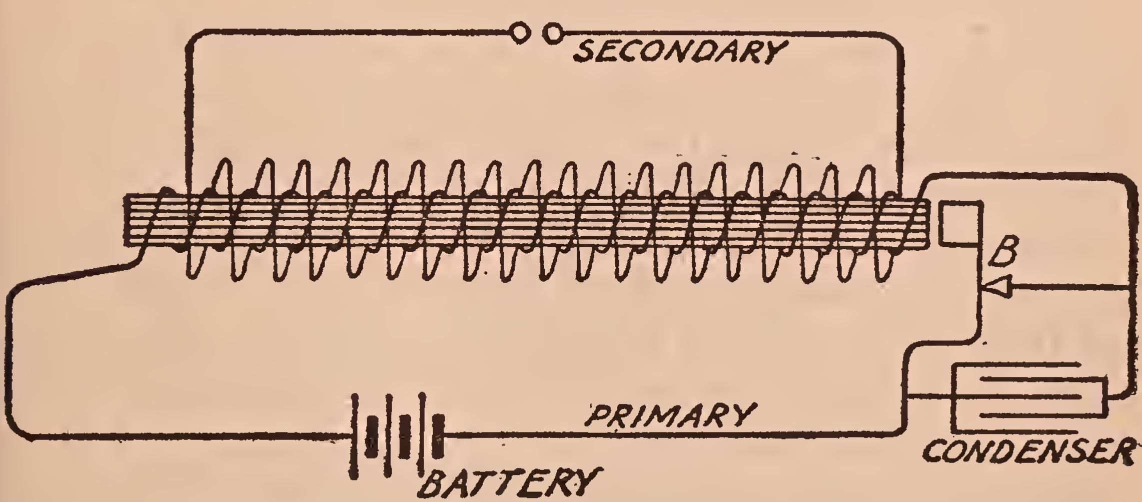

FIG. 95. THE HOOK-UP OF AN INDUCTION COIL.

You must use the astatic needles in the galvanoscope and you may need to use the 110 volt control panel with a 110 volt supply to get a large primary current.

HOW IT WORKS.—The hook-up of an induction coil is shown in Fig. 95. Omitting for a moment a con-

sideration of the condenser, we have a primary circuit very much like an electric bell or buzzer. The point B is where the circuit is automatically made and broken. The soft iron armature A is attracted by the iron core of the coil. This breaks the circuit at B, and the primary coil loses its current and its magnetic effect. Then the spring S moves the armature back, and contact is again made at B.

The Vibrator makes and breaks the current very rapidly. This results in the induction of a. c. in the secondary, which usually having many more turns than the primary, produces a high voltage.

The Condenser.—When the current is broken at B a spark is produced, and the current flowing through that spark does not stop suddenly. The quicker the current changes from its normal value back to zero, the more quickly does the magnetism disappear. Hence the flux cuts the secondary more rapidly.

With a condenser connected as shown, when the current is broken at B, the electrons forming that current rush into the condenser, instead of making a spark. This makes the break a snappy one and increases the voltage induced in the secondary.

Uses of the Induction Coil.—One use is to obtain an alternating current from a d. c. supply but the transformer action whereby we obtain a great step-up in the voltage makes the induction coil an important source of jump sparks.

The very high voltage from the secondary will jump between the *points* of a spark plug and ignite explosive mixtures.

Ignition.—All engines using gas, gasolene, kerosene etc., for fuel, operate on the principle of exploding the compressed vapor of this fuel.

An electric spark is used to explode the vapor. Two distinct types of ignition systems have been developed. The "make and break" often used on slow speed and

motor boat engines; the "jump spark" used on high speed engines and those whose speed must be varied a great amount.

THE MAKE AND BREAK SPARK.—The firing mechanism is built on a plate or plug which fits into the side of the cylinder very near the top. As shown in

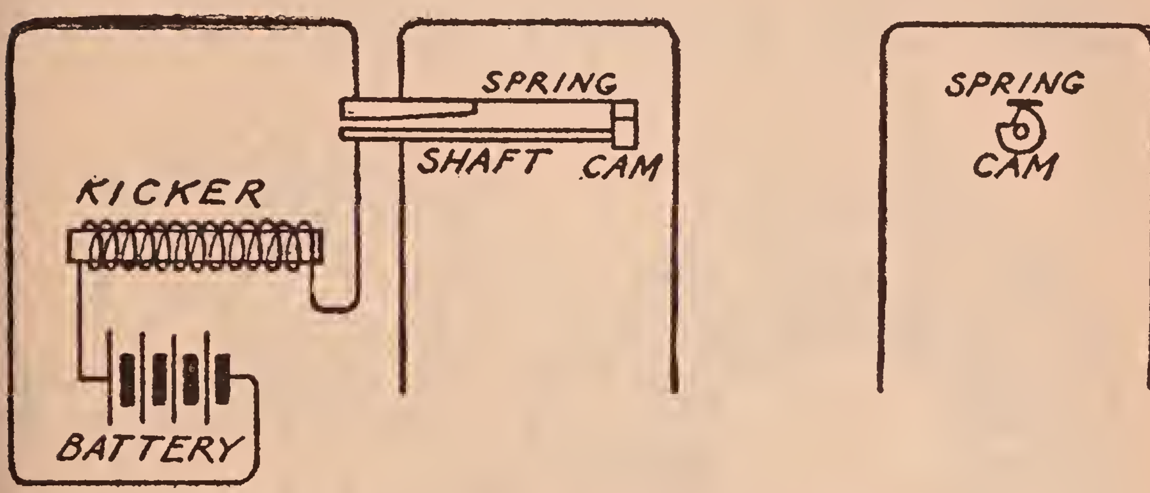

FIG. 96. MAKE-AND-BREAK IGNITION.

Fig. 96 a stationary rod holds a spring and a rotating shaft carries a cam.

The electrical circuit is as shown. The *kicker* or kicking coil is a coil of wire wound on an iron core. When the cam makes contact with the spring a current flows. At the proper instant the cam moves away from the spring, and the circuit is broken. A spark occurs at this gap.

The magnetism of the coil dies away and cutting the turns of wire in the coil induces in them a current which makes extra electrons move. These electrons crowding at the gap cause a much heavier spark than the battery alone could make.

THE JUMP SPARK.—There are several different types of jump spark ignition systems. Some use a battery, others a low voltage magneto and a few a high voltage magneto as the source of energy.

In some systems the current at a low voltage is con-

nected in turn by a timer, to each of a set of induction coils, there being one coil for each cylinder and each coil serving one spark plug.

Another method uses one induction coil and distributes its output to the different spark plugs in the proper order.

Ford Ignition.—A system combining a low voltage magneto with low tension (voltage) distribution

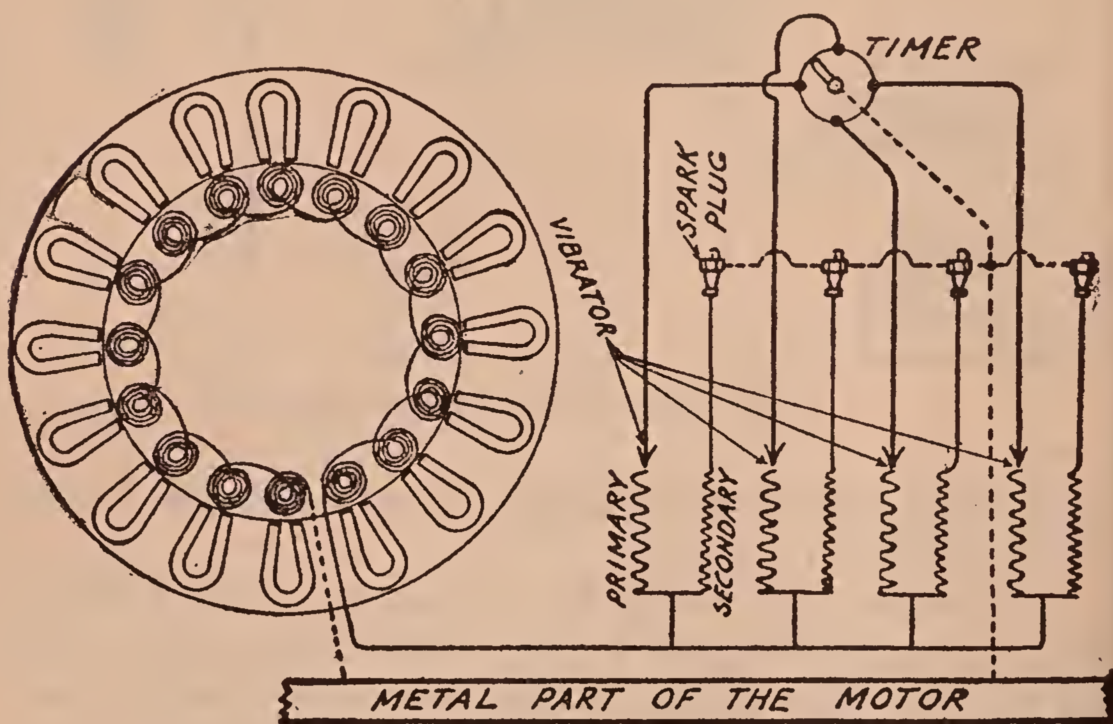

Fig. 97. Low Tension Timer Ignition System.

avoids the need for very good insulation of moving parts. The essentials of this system are shown in Fig. 97.

The 16 horseshoe magnets on the flywheel induce current in the coils fastened on the frame of the motor. This current flows from the magneto to the four induction coils. They are connected in parallel, but current flows through but one at a time.

As the timer connects the low voltage current to the primary of a particular coil its vibrator acts and

there is induced in the secondary a high voltage which is delivered to the spark plug.

A lot of wiring is saved by using the frame of the motor as a path for the current. The primary circuit is completed from the timer's rotating contact through the metal of the motor back to the magneto. The

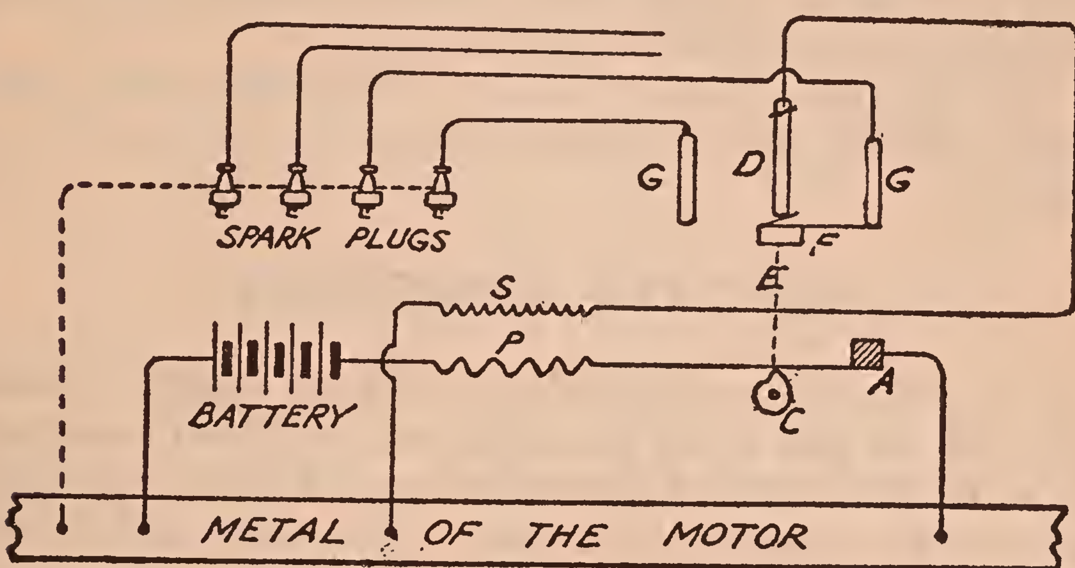

FIG. 98. SINGLE COIL, HIGH TENSION DISTRIBUTION IGNITION SYSTEM.

completion of the secondary circuit is obtained by connecting the primary and secondary windings as shown in Fig. 97. Thus the secondary current can flow from the plugs through the metal of the motor to the rotating contact of the timer and thence through the primary winding. The dotted lines in the diagram represent paths through the metal of the motor.

ONE COIL SYSTEM.—From a battery as in Fig. 98, the current goes through the primary of an induction coil and then to a mechanical make and break. This acts as a vibrator for the coil. The cam C moves the spring against the contact A and allows it to snap away suddenly. The cam shaft is geared to make as many revolutions to one of the motor as there are cylinders in the motor. In this way the secondary sends out a high voltage impulse for each cylinder.

Connections from this single coil to the spark plugs are accomplished by a distributor. To its central connection D the secondary current flows. A rotating block E makes a firm yet easily rotated contact with D. The same shaft drives both C and E so they are properly timed. The spring contact F almost touches the posts G in turn. There are as many posts as cylinders and each is connected to a spark plug.

The diagram shows how both the primary and secondary circuits are completed through the metal of the motor.

FAMILIAR QUESTIONS

Can you walk on a third rail without injury? Yes. But you can not touch the third rail and the ground at the same time without experiencing a shock. For you would then complete a circuit. Since the third rail serves the same purpose as a trolley wire, you could hang from a trolley wire without injury as long as you did not also touch anything connected to the ground.

How can birds sit on a 22000 *volt trolley wire?* For the reasons given above. There is no circuit through the birds, no passage of electrons and hence no ill effects.

Can 110 *volts kill you?* Were this not a serious matter I would make a joke and say that volts cannot kill you, it is the amperes that do it. The resistance of the skin is so high that 110 volts can not send a dangerous current through a strong healthy person. But a scratch or a sore may reduce the resistance of the skin at that spot. Then if we complete a 110 volt circuit, we may receive an injurious current, particularly a person with a weak heart. Make it a rule not to touch live wires.

How many volts will it require to run my motor? Enough volts to push sufficient amperes through all the resistances of the circuit, so that the motor will run.

It is the amperes that do the work. Amperes are

electrons in motion and they will not move unless pushed.

The pushing force in a circuit is measured in volts.

What is a 50 watt incandescent lamp? It is a lamp that when placed on a 110 volt circuit allows 0.45 amperes to flow. The lamp is designed so that this current will heat the filament as hot as it is wise to heat it.

On the 110 volt circuit for which this lamp was designed it takes 50 watts of power to operate it.

You can purchase a 50-watt lamp for 120 volt circuits. These lamps have a slightly higher resistance. On the proper circuit they use 50 watts of power.

The candle power of a 50 watt lamp depends on whether it is a vacuum or a gas type and whether it is used on the circuit for which it was designed.

Do abandoned steel ships move to the poles? No. The magnetic force of the earth is a twisting force. It will not pull.

CHAPTER XII

RADIO

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RADIO

Radio is so named because the energy used to transmit signals is *radiated* into the air at the sender's station. By signals I mean voice, music, interrupted or varied currents of electricity.

Radio used to be called *wireless*. Most people do not realize that our supposedly new radio is the same old wireless of the early Marconi days in 1894. In 1899 messages were sent across the British Channel and war ships were telegraphing to each other. In 1902 messages were telegraphed across the Atlantic Ocean by wireless.

The broadcasting stations are using the same methods for sending out waves as the amateurs are using, but of course with much more powerful transmitters.

Folks Using Radio.—Communication between ships and ships and shore includes distress calls, radio compass work and fog signals. The transatlantic and transpacific ocean traffic is very heavy. Navy and Government business is utilizing radio to a great extent. The broadcasting furnishes entertainment for millions. The transcontinental communication by radio is growing. Finally 1200 boys and men talk and telegraph by radio every evening after 10 p. m. During the month of March, 1923, they sent and delivered 160,000 messages.

Before studying the electrical part of radio it would be well to take a glance at the practical side of it. A trip to a few sending stations would be interesting and

instructive. I wish you to notice the difference in the apparatus used to produce the same thing.

Sending Stations.—SPARKS.—Down the street is a boy friend of mine. He is signalling to another boy in a distant city. He has a Ford spark coil, a condenser, and a place for the spark to jump across.

He is sending short and long currents into the induction coil, thus sending short and long showers of sparks from the coil. The electricity from the sparks passes along his antenna and forms radio waves in the air.

On any ship you will find a similar sending set with larger induction coils, bigger and better apparatus throughout, and a larger current used to send.

ARCS.—In the sending sets of the U. S. Shipping Board and the Naval Stations a flame between two carbon rods sends out the radio waves.

ALTERNATORS.—There are a few big stations that use specially designed alternators to generate radio waves.

VACUUM TUBES.—Specially constructed vacuum tubes containing a filament, to be lighted, like an incandescent lamp, a metal plate and a wire net work, are used to send out waves.

These vacuum tubes are used by the amateurs and the broadcasting stations. Originally made in small sizes about as large as an ordinary incandescent lamp and giving out 5 watts, they are now made in huge sizes furnishing 50 kilowatts.

Waves.—Every one of these people in each station was engaged in sending out waves. Certainly we must learn something about waves.

A wave motion is a method of transferring energy without transferring any material. One way of destroying an enemy's wooden ship would be to throw something violently at it. But even the ancients knew that concentrating the sun's rays on a wooden ship,

by means of huge bowl-shaped mirrors of polished metal, would furnish enough heat to set it on fire—provided of course the ship was in the same place long enough for the heat to accumulate. Heat is carried by a wave motion.

If there is a chip of wood out in a pond quite out of my reach, I may move it up and down by throwing a stone, hitting it. Or I may drop a large stone into the water near the shore, and in this way I shall start a series of waves, which spreading out will travel to the chip and move it.

Although the wave motion travels far, the material in which the wave is formed and through which the wave travels does not move much.

When the wave in the water reaches the chip, it rises and moves forward with the wave a bit. Then as the wave passes on, the chip slides down the back of the wave to the place where it was before. It floats on the same old water in the same old place. The wave moves forward to its destination but the water stays where it was.

When the wind blows across a field of grain, you can see a wave motion moving through the tops of the stems. You know that the stems are firmly rooted in the soil, and do not move across the field. You know that the tops of the stems merely vibrate to and fro, yet the wave does advance; you can see it do so.

There are two kinds of waves for us to study in Radio Telephony, sound waves and radio waves. I pick out radio telephony because that is the most popular branch of radio.

Since all waves have some features alike we will take up sound and radio waves discussing their speed, frequency, wave length and amplitude.

An Interruption.—Some one, age 14, looking over my shoulder at this point, asks me: "Have you told them how a receiver works?" I have looked him

straight in the eye and replied. "No. How can I do that until they know what it is that the receiver is receiving?"

Sound Waves.—Anything that sets material vibrating at a rapid rate creates a sound wave. Now a sound wave is not sound. It takes three things to make a sound.

1.—A body in vibration to start the sound waves.

2.—A material to carry these waves.

3.—An ear and brain to change these waves to the sensation of sound.

In a radio receiver the telephones or head set or phones, as they are variously called are the bodies that start air into vibration. This causes sound waves which the air carries to your ear and you hear.

Speed.—The speed of sound is 1090 feet per second on a freezing cold day in winter, and about 1120 feet per second on a summer day.

Frequency.—While listening at the phones of a radio receiving set this set causes the diaphragms of the phones to vibrate to and fro. Sometimes they vibrate at such a rate as would cause them to make 200 to and fro motions in a second, provided that they continued to vibrate as long as that, at that rate. This would be a frequency of 200. At another time perhaps for one one hundredth of a second the diaphragm vibrated regularly and made 20 vibrations. That would be at the rate of 2000 in one second, or at a frequency of 2000.

The frequency of the vibrations is the rate of vibration. Hence frequency is the number of vibrations per second.

A vibration of anything means going from end to end of a region and back again, including being all ready to do it again. Take the letters *v i b r* as they stand. If the dot over the *i* moved over to the *r*, back to the *v* and to its regular place again, it would have

made a complete vibration. You could say that the dot has made an *oscillation.*

Since this kind of a trip is like that which the boy made on page 50, which I would like you to read again, we may say that this dot over the *i* has completed a cycle.

The word frequency means the same as cycle. We speak of a 500 cycle a. c., whose frequency is of course 500. When referring to a body causing a sound we should mention its frequency. It would be correct to say, "A 1000 cycle sound wave," but we do not. We say the equally correct thing, "Its frequency is 1000."

Wave Length.—When a wave motion which will cause you to hear sound is passing through air, it may be photographed. This picture shows the air to be compressed at some places and expanded at others. By expanded I mean less air than usual, and by compressed I mean more air than usual is at those places.

The distance from one place of greatest compression over across a place where the air is stretched or expanded to another spot of greatest compression is called a *wave length.*

Wave Length Formula.—When a vibrating body at a frequency of 500 sets up a sound wave in air, this wave advances at the speed of 335 meters a second.

The first puff of air which left the body has created a series of compressions. At the end of one second 500 of these compressions are distributed over a distance of 335 meters, all evenly spaced with an equal number of expansions of the air in between.

The distance a particle of air moves in completing a cycle is a wave length. Also the space occupied by a compression and an expansion of the air is a wave length. So dividing 335 by 500 gives 0.67 of a meter as the length of what is called a wave.

This is true of all wave motions. Divide the velocity by the frequency and get the wave length.

Amplitude.—When we bang a drum hard it gives out a loud sound; strike softly and the sound is not so loud. We say that the sound waves differed in *amplitude*. Really then amplitude means energy, for the more energy in the wave the greater will be the impression on the ear.

There seems to be one particular rate of vibration at which the drum head likes to vibrate, and vibrations of that frequency persist and do not die out quickly.

Why it has a natural frequency I do not know, just as there are many things we do not know. Nature decreed that it should be so.

Hit a drum softly. The calfskin head vibrates at its natural frequency, sends out a sound wave of the same frequency and I hear a sound in my ear of that frequency. Yes, that sound wave had a certain wave length, but I really do not care about that. Since a frequency started it and I hear it because of the frequency with which my ear drum is beaten upon, let us stick to frequency.

Light Waves.—Light differs from sound, yet both are waves. But the only resemblance between light waves and sound waves is in being ever expanding shells of disturbance. Here the resemblance stops with a jolt.

To create light, electrical charges vibrate. The frequency of this vibration is an enormous number. The speed or velocity of advance is 300,000,000 meters a second. Light could go around the earth 7½ times a second.

To get the wave length we divide 300,000,000 by the frequency and have the wave length in meters. Since the frequency is an enormous number and the wave length a reasonably easy number to say, when discussing light we talk of wave length.

Invisible Light.—All waves of exactly the same character as light waves are not visible. Some have a

frequency too high to be detected by our eyes; again, other waves have too low a frequency to be seen.

Electromagnetic Wave Motions.—X-rays, visible light, and heat waves are all alternate electric and magnetic energy radiated from bodies. They are formed by the energy thrown out from electrons as they revolve in atoms of materials. From electrical charges vibrating in paths from a few feet to ten miles long we obtain radio wave motions.

Radio Waves.—Electromagnetic wave motions produced by the surging or oscillating of electrical charges at a frequency of from 15,000 up to 3,000,000 are those referred to today as radio waves.

Velocity.—Their velocity is the same as that of light, being 186,000 miles a second, or, since radio engineers use the metric system, we will say 300,000,000 meters a second.

Frequency.—The frequency of the electrons as they oscillate in any kind of a radio frequency generator is the frequency of the radio wave motion.

Wave Length.—It is rather unfortunate that we got in the way of talking about 200 meter, 360 and 400 meter waves, meaning that their wave lengths were 200, 360 and 400 meters. Unfortunate, because it is the frequency of the vibration or the frequency of the oscillation of the electricity at the generating station that puts the broadcasting into the air as a wave of certain length.

Your radio receiving set will absorb energy well or badly, according to the frequency of the energy that passes your home. When you have it adjusted correctly only one group of frequencies will be absorbed and the others rejected. So we should talk about radio in terms of frequency.

We all fell into the habit of talking about a. c. house and factory supply as 60 cycle a. c. We talked about the frequency of audible sound as being for musical

sounds from 16 to 3000 and for speech from 200 to 2000. True, we usually say a pitch of 200 to 2000, but pitch is but another word for frequency.

But when we came to radio we were too lazy to say a frequency of 833,000 or 750,000, and said instead 360 or 400 meters.

Rule for Wave Length.—Divide 300,000,000 by the frequency to obtain the wave length in meters.

If you know the wave length, divide it into 300,000,000 to find the frequency.

Amplitude.—Nearly every picture that the word amplitude brings before the mind will give a wrong impression when applied to a radio wave motion. Like many technical words handed down to us, it has a definite meaning quite different from that conveyed by the sound of the word. Amplitude means Energy.

Imagine a real dyed-in-the-wool scientist taking a little recreation in the breakers at the seashore. They are cute little ones about four feet high and roll in regularly as a clock, every three seconds.

"Constant frequency of ⅓," says the scientist, as he turns his back and enjoys the regular slap, slap of the breakers on his back. "Constant amplitude, also," says he, as they each hit him with a regular and equal force.

Then suddenly, *Bing!* He receives a wallop from an eight-footer. Over he goes. On struggling to his feet, precisely three seconds after the *bing,* comes another wave, eight feet high. *Bang!* Over he goes again. Up he comes, and in two seconds is braced for the next wave. On they come, three seconds apart but eight feet high.

"Well," says our scientist, "the frequency of these waves is the same, but their amplitude has greatly increased."

Remember that amplitude means energy.

Production of Radio Waves.—First we want electrons to surge to and fro, or oscillate, as we usually say. A spark coil, a specially designed high frequency alternating current generator, an arc lamp with the flame between the carbons at proper adjustment or a "vacuum tube" will all start electrons oscillating.

We now wish to encourage those electrons that are oscillating at a definite frequency to continue at that frequency. We also wish to discourage and perhaps entirely prevent electrons from oscillating at any different frequencies.

We must also cause the electrons to set up an electromagnetic wave motion.

There is so much here that needs explaining that I will start with a little talk on a. c. and then take up the points in the production of a radio wave motion one at a time.

A SHORT TALK ON A. C.

Mutual Inductance.—In describing the induction coil and the transformer it was stated that the magnetism of the primary coil transferred energy into the secondary. The name of this process is *induction,* or in a more explaining way, electromagnetic induction.

The current which was generated in the secondary coil produced a magnetic field, which of course must transfer energy into any coil near it. The primary coil is very near. So the secondary acts back on or reacts, as we call it, on the primary. This process of mutual action and reaction is called *mutual inductance.*

Any coils in any electrical apparatus near each other will have a mutual inductive effect on each other. Placing these coils with their axes at right angles to each other reduces the mutual inductance to zero or almost zero.

In radio work the amount of mutual inductance between two coils is called the *coupling.*

Coupling.—Loose coupling is obtained when the coils are far apart or at an angle to each other. Tight coupling is obtained by placing axes of coils parallel or nearly so, and near each other.

When one coil is within the other, axes being parallel or nearly so, we have very tight coupling.

Self Induction.—*Experiment 47.*—Connect 6 dry cells in an arrangement of 3 in series and two rows in parallel. Solder one wire from this battery to the handle end of a coarse cut file. Holding the other wire from the battery in your hand, draw it along the rough surface of the file. Do this quickly and then take wire from the file, else the short circuiting will injure the battery.

You will not see any sparking at the breaks of the current caused by the rough teeth of the file.

Insert in the wire you had in your hand any convenient electromagnet, a bell, primary of an induction coil, with vibrator screwed up firmly. When you draw the wire across the file you now get a series of sparks.

These sparks are caused by the electromagnetic induction of the magnetic field of this coil *on itself*. This action is called self induction, or more briefly, *inductance.*

All electrical apparatus containing coils will show this effect of *inductance.* Since every wire carrying current has a magnetic field around it, even straight wires show some inductance.

Radio sets contain coils, thus causing, by mutual induction, energy to be transferred between them; sometimes to places where we do not want it. We then turn these coils at right angles to each other to kill the inductive effect.

Reactance.—Inductance causes coils to offer more opposition to a. c. than it would to d. c., because the

a. c. is compelled to build up a magnetic field twice as often each second as the number expressing its frequency. This extra work that d. c. does not do reduces the amount of current which the a. c. e. m. f. can force through the inductive circuit.

This extra resistance to a. c. we call *reactance*.

To calculate the reactance of an inductive circuit multiply the frequency of the a. c. in it by the henrys of inductance of the circuit and then by 6.3; the answer will be in ohms.

CONDENSERS.—When there is only a condenser in a circuit it is electrically combined with the resistance of the wires leading to and from it. This condenser offers opposition to the oscillations of the electrons. This we call capacity reactance.

The capacity reactance of a condenser is calculated by multiplying the frequency of the a. c. in the circuit by the capacity in farads and then by 6.3, this answer to be divided into 1. The final answer is the capacity reactance in ohms.

CAPACITY.—A condenser in a circuit offers a place for electrons to accumulate. If a coil was choking back a. c. and a condenser were placed in the circuit, then the condenser would afford a waiting room for the electrons that could not get through the coil.

COMBINED INDUCTANCE AND CAPACITY.—Please read the last paragraph again and then imagine a circuit with a coil of 15,600 microhenrys inductance in series with a condenser of 100 microfarads capacity and a. c. supplied to this circuit at a frequency of 127.

The coil says to the a. c. e. m. f., "Wait. You must devote part of your pressure to forcing my magnetic field into space." The condenser says, "Come on, you electrons, there is lots of room here."

The result is interesting. While the coil is acting as a dam to the electrons at one point in this series circuit, which would result in small flow of electrons from the

a. c. supply, the condenser is acting as a waiting room for those electrons that can not go through the coil. Hence the same number of electrons flow from the supply as if the coil and condenser were not there.

We see, then, that in a series circuit the inductance and capacity may be made to balance each other, and the same a. c. will flow as if the condenser and coil were not there.

Something Odd.—Suppose you had an a. c. supply circuit and that you attached to it, just as you would a lamp which is in parallel, a coil whose inductance is 10420 microhenrys. To this same circuit attach a condenser of 150 microfarads capacity. The coil and condenser will be connected in parallel on the same circuit.

After a fraction of a second the coil and condenser become charged and then the fun begins. The a. c. reverses its direction. The coil says to the onrushing electrons "Wait." Seeing a convenient waiting room, the condenser, they rush in there. Just at the moment when the coil is ready to conduct electrons, the condenser is getting uncomfortably full and the electrons rush out and dash through the coil.

In this way there is a continual flow of electrons forming an a. c. through coil and condenser and yet not a single electron is sent out from the supply. The generator in the power house supplies a. e. m. f. but no movement of electrons. If the generator pressure is 100 volts, and frequency 127, there are 12 amperes flowing through coil and condenser and no extra amperes flowing through the supply circuit from the generator.

These queer things about a. c., coils and condensers are utilized in transmitting and receiving radio signals.

Distributed Capacity.—All wires running close to each other and parallel form small condensers. All coils have a condenser effect between the wires of their windings. It is true that certain coils are wound in a

special manner to reduce this capacity, yet some is there. These capacities are called the *distributed capacities,* as contrasted to the concentrated capacity of a condenser.

When figuring what a circuit will do, do not forget the distributed capacity.

The Queerest Thing Yet.—The capacity of a condenser depends on the frequency of the a. c. that charges it. The change is not great, but sufficient to be of great importance in the transmission and reception of radio signals

Impedance.—The total opposition of a circuit to a. c. is called the impedance. It is composed of the resistance, the inductive reactance and capacity reactance all combined.

The impedance of any circuit may be very low if the inductive and capacity reactances cancel each other.

Since the capacity of a condenser changes with the frequency it is possible to have a coil and a condenser whose reactances cancel at only one frequency.

Such a circuit would have a high impedance at all but a few frequencies. At these few the impedance of the circuit would be low, and at one of these frequencies the impedance would be very, very low.

This effect of very low impedance at one frequency is of great importance in the sending and reception of radio signals.

Getting Radio Waves Into the Ether.—There are several things to do. 1. We must make electrons oscillate at high frequency. 2. Compel them to oscillate at a definite frequency. 3. Let them form electromagnetic waves.

1. The most economical source of oscillating electrons is an alternating current of radio frequency from an a. c. dynamo.

On account of the large bulk and weight of these dynamos, when moderate power is sufficient vacuum tubes are used to generate the a. c. of radio frequency.

The power for the trans-oceanic traffic is furnished by a. c. dynamos and the power for the broadcasting comes from vacuum tubes.

2. To compel the electrons to oscillate at a definite frequency we need a circuit of certain electrical character.

Let us first agree exactly upon what we want to do. Suppose that I have a license from the Government of the United States to transmit on a 400 meter wave. What really does that mean? That I am permitted to radiate into the ether electromagnetic waves caused by electrons surging to and fro (or oscillating) at a frequency of 750,000 (or making 750,000 oscillations per second).

Suppose then I arrange a circuit of the proper electrical length so that it takes 1/750000 of a second for an electron to make a complete trip through and back. Then I will have an oscillation circuit with a natural period of 1/750000 of a second, and the frequency of the oscillating electrons surging in it will be 750,000.

When you think it over it seems as if the time occupied in going through the oscillation circuit were the important thing. It is. How would it be, then, instead of making the oscillation circuit so long and hence bulky, to arrange to have the electrons delayed. A clever arrangement of coils will not only put a long electrical circuit into a small space but the inductance of the coil will delay the electrons. Condensers may also be used, furnishing places for the electrons to hide in for fractions of seconds, thus delaying them.

Rule for Wave Length.—Radio engineers have found that 1885 multiplied by the square root of the product of the capacity in microfarads and the inductance in microhenrys will give the wave length radiated by an oscillation circuit. The wave length divided into 300,000,000 will give the frequency of the oscillating electrons.

An Actual Circuit.—An oscillation circuit will have the general form of Fig. 99A. The source of radio frequency alternating current (r. f. a. c.) fur-

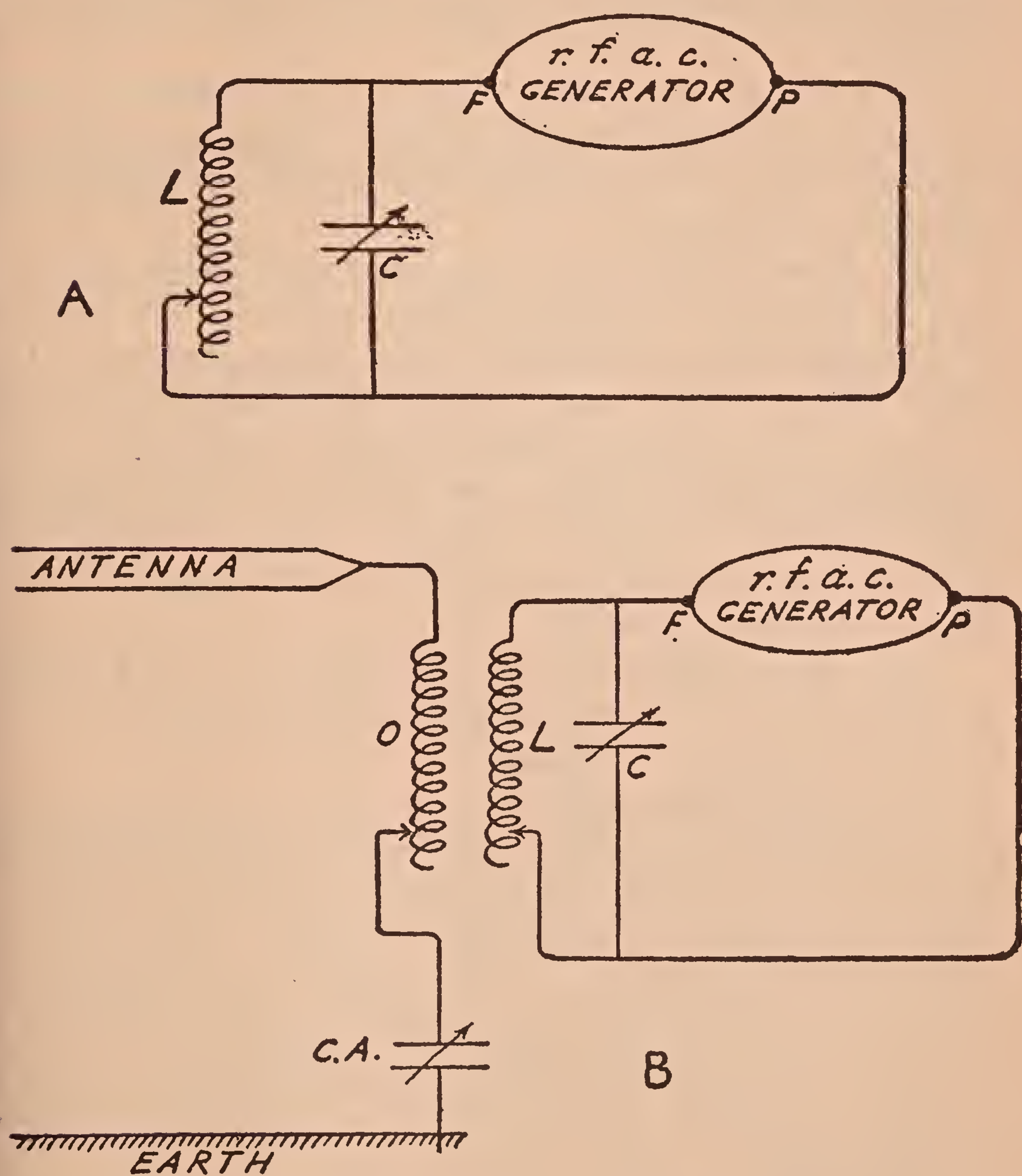

Fig. 99. Oscillation Circuits.

nishes oscillating electrons and the adjustable inductance L and the variable condenser C may be made to furnish just the proper amount of delay, so that an electron needs 1/750000 of a second to oscillate from P to F and back again.

What Carries the Radio Wave Motion to Us?—It seems that no material is needed. The radio waves pass through air, brick and stone yet do not use these materials to travel on. Radio waves go through a vacuum.

Since we do not know what the radio waves travel on and yet feel that they must have something to be in and travel on, we use the word *ether,* to express an imaginary substance.

The *ether,* then, is in a vacuum and in everything, and on this *ether* the radio waves travel.

Getting Into the Ether.—We now wish to form radio waves in the ether. The closed oscillation circuit of Fig. 99A will not radiate energy well. An open oscillation circuit is what we need. In Fig. 99B an open oscillation circuit is shown. It is composed of the antenna A, an inductance O, a condenser C. A. and a ground connection.

With the adjustment of the inductance O and of the condenser C. A. we may make the time constant of the circuit 1/750000 of a second.

As the electrons oscillate in the closed circuit by the mutual inductance between the coils L and O energy is transferred from the closed circuit to the open circuit. The combination of the coils O and L is called an oscillation transformer. The tighter the coupling between these coils the more energy will be transferred.

But it is not merely energy that we want, it is the transfer of energy at one particular frequency and not at any other.

TRANSFERRING OSCILLATIONS.—To explain why an electron in L oscillating at a frequency of 750,000 will cause an electron in O to oscillate at the same frequency I must use a simpler diagram.

Since the coil L is merely a long wire coiled into a small space, let us unwind it and stretch it out straight, as in Fig. 100A. Let us do the same with the coil O.

Remembering that electrons dislike and repel each other, let us start to find out how the frequency in L is transferred to O.

In any copper wire (or any material, in fact) there are a few electrons wandering around in an aimless

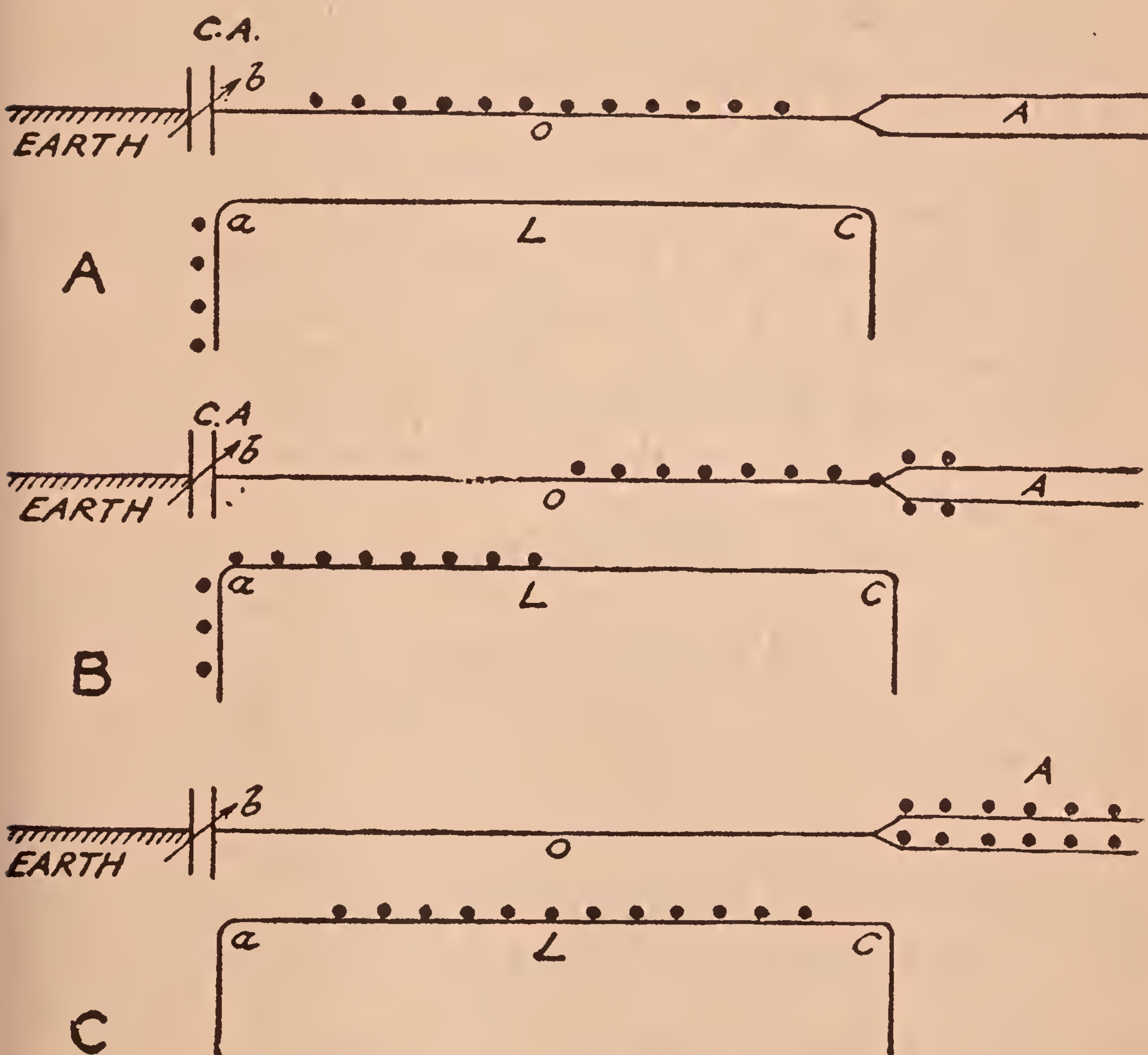

Fig. 100. Transferring Oscillation.

haphazard fashion. When an electron from the r. f. a. c. generator arrives at the point *a* on the wire L it will repel any wandering electrons at *b* on the wire O which are moving towards *c*. As the electron at *a* moves along L to *c* it drives the electron on O which was at *b* ahead of it. This crowds all movable electrons in O up into the antenna A.

The situation is now as shown in Fig. 100C; a lot

of electrons are on L and they have repelled an equal number of the electrons from O into the antenna A. The 1/750000 of a second has now passed and the r. f. a. c. generator reverses its e. m. f. and calls the electrons on T back. (Or pushes them back.)

So many electrons are crowded on the antenna A that there is a pressure tending to push them out again. As the electrons on T retreat from *c* through the point *a*, the electrons come rushing out of the antenna, and finding those in T "on the run," those in O actually help to push those on T along back to the generator.

In 1/750000 of a second the r. f. a. c. generator reverses and the whole cycle of events occurs over again.

Thus the oscillating electrons in the closed circuit of Fig. 99B create an oscillation of electrons in the open circuit at the same frequency.

The same thing will happen in precisely the same way even if O and L are the same wire. The energy of the r. f. a. c. may be applied directly to the open circuit and the oscillations of electrons will take place as described. Such a combination of the circuits is shown in Fig. 101.

Please notice that the antenna and ground make a huge condenser. Fig. 99 makes this clear. Notice that this condenser may be charged and discharged at the frequency of 750,000. Fig. 100 and the discussion of that illustration shows how this may be done.

What the Antenna Does.—The antenna, which for transmitting is a group of wires parallel to each other, hung high up in the air and insulated from everything but the transmitter, forms one plate of a condenser. The earth is a conductor and is connected to the transmitter. The air between the antenna and the earth forms the dielectric of the condenser.

The r. f. a. c. generator through the oscillation circuits charges this condenser at a frequency of 750,000. This condenser can not discharge through such a thick

layer of air as there is between the antenna and ground. Nor can this condenser discharge through the transmitting set which is connected to the antenna and to the ground, because the set is pushing out energy with such force. You can't pour a pitcher of water into a hose from which water is flowing with some force. Hence the charge leaks off the antenna at a frequency

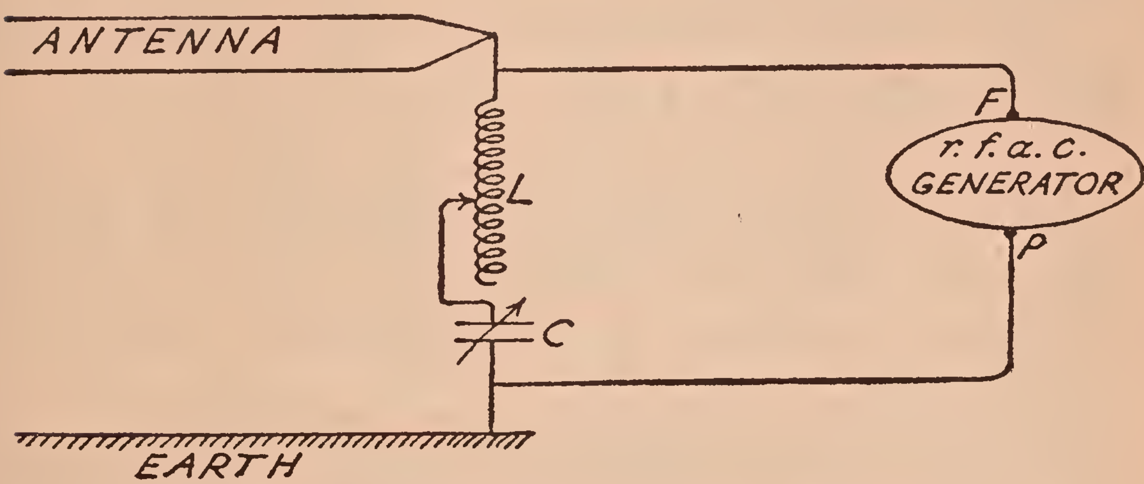

FIG. 101. SINGLE CIRCUIT TRANSMITTER.

of 750,000, in much the same way as electrostatic charges leak from the lightning rods of a building.

This leakage from the antenna-earth condenser sets up what we call an electro-magnetic wave motion which has a frequency of 750,000 and a wave length of 400 meters.

For a wave length of 360, read the last six pages again, using 833,000 for the frequency, 1/833000 of a second for the time constant of the circuit and 360 for the wave length.

These waves carry the energy which is received, and as this energy is spreading out as the waves advance, the further away you are from the transmitting station the less energy you receive.

Radiating Only One Wave Length.—Only one wave length should be put into the ether. In this transmitter which I have been describing the method of tun-

ing the circuits for oscillations of a frequency of 750,000 has been explained. A certain combination of inductance and capacity will do this. This combination effects two things. First, the character of the circuit compels electrons to take 1/750000 of a second to oscillate. Secondly, the impedance for the frequency of 750,000 is so low that very little energy produces a large flow of electrons.

Any electrons oscillating at any other frequency will find the impedance so great that their energy will be used up very quickly.

In the circuits as we have tuned them for a frequency of 750,000 only these oscillations will persist. All other frequencies will die out, due to high impedance. As we say in technical slang, "They are damped out."

Listening In.—We will now proceed to absorb the energy of the radio wave motion. Then translate the alternating current which is at radio frequency to a direct current interrupted at audible frequency. The telephone receiver will then respond to the d. c. interrupted at audible frequency and we will be listening in.

The various steps in the process are: Absorption of the energy from the electromagnetic waves. Permit only those of one frequency to set up oscillations. Transform these r. f. oscillations which are a. c. into a varying d. c. of audio frequency. Then the phones do the rest.

Apparatus for Receiving.—1. The absorber, which is the condenser formed by the antenna and the ground. 2. The selector of the desired frequency, which is the tuner. 3. A rectifier or changer of r. f. a. c. to r. f. d. c., which is called by every one a *detector,* although it does not detect; it rectifies. This may be a crystal or a vacuum tube. 4. A device to change electrical impulses of d. c. into sound, which is

the phones. Fig. 102 gives several hook-ups of receiving circuits.

WHAT DOES RECEIVER MEAN?—The combination of a tuner and a rectifier is called by the general public a "receiver." A receiving set is a better name. To your radio receiver you attach telephone receivers. This makes confusion. To avoid this we will call a combination of a tuner, a rectifier and telephone receivers by the name of a receiving set, and the telephones we will call phones.

A pair of phones with a band to hold them on the ears is frequently called a head set.

A single phone, usually of special construction, attached to a horn to reinforce the sound, is called a loud speaker.

Absorbing the Energy From the Radio Waves.—Erect an antenna as high as possible from the ground. For reception, a single wire is almost as good as several. Attach your receiving set to the ground and to the antenna.

The condenser formed by the antenna and ground is charged by the radio waves passing it. It can discharge through your open oscillation circuit and in doing so would set up oscillations at many frequencies were it not that you have adjusted the inductance and capacity of the circuit to encourage by low impedance a particular frequency and to damp out by high impedance to them only, all other frequencies.

Selecting the Desired Frequency.—Since the antenna is probably 100 feet long and the "lead in" from the antenna to the receiving set may add another 50 feet of wire, your adjustable inductance and capacity will have a hard job of exactly tuning the open oscillation circuit. It is hard for a small dog to wag a large tail.

But you may time the closed oscillation circuit of Fig. 102A very accurately, or "sharply," as we say,

for here the inductance L and the condenser C contain a large proportion of the impedance of the circuit. Here a large dog wags a small tail.

The real *selector* of the desired frequency is the closed oscillation circuit, which enables the receiving set to be tuned *sharply*. A tuner that can be tuned accurately is said to be *sharp*. A very sharp tuner is said to be *critical*. Such a tuner must be tuned exactly, else the signals are very weak.

Interference.—Poorly designed tuners will not prevent you from hearing several signals at the same time. This is called *interference*. The process of removing interference by adjustments of the tuning circuits is called "tuning out interference."

Receiving Circuits.—There are three distinct parts to each receiving set, the tuner, the changer of a. c. to d. c., and the phones.

When we talk of this and that kind of a circuit we are referring to the arrangement of the parts of the tuner and to the devices that are assembled to make the tuner.

Double-Circuit Tuner.—In Fig. 102A we have an open oscillation circuit consisting of the condenser formed by the antenna and the earth, together with a connection between the antenna and earth. This connection consists of an inductance O and a condenser C. A., both of which are variable so that we may tune the open oscillation circuit.

Coupled to the inductance O is an inductance L. This combination may be made in different ways and may be known as a loose-coupler, a vario-coupler, or coils with fixed coupling. The names are taken from the mechanical arrangement of the coils and are fairly indicative of their arrangement.

The inductance L is variable and is shunted by the condenser C. Thus the closed oscillation circuit may be tuned.

Since we have two oscillation circuits this tuner is called a Two-circuit or a Double-circuit Tuner.

When the crystal was displaced by a vacuum tube, extra circuits were added but the old name stuck.

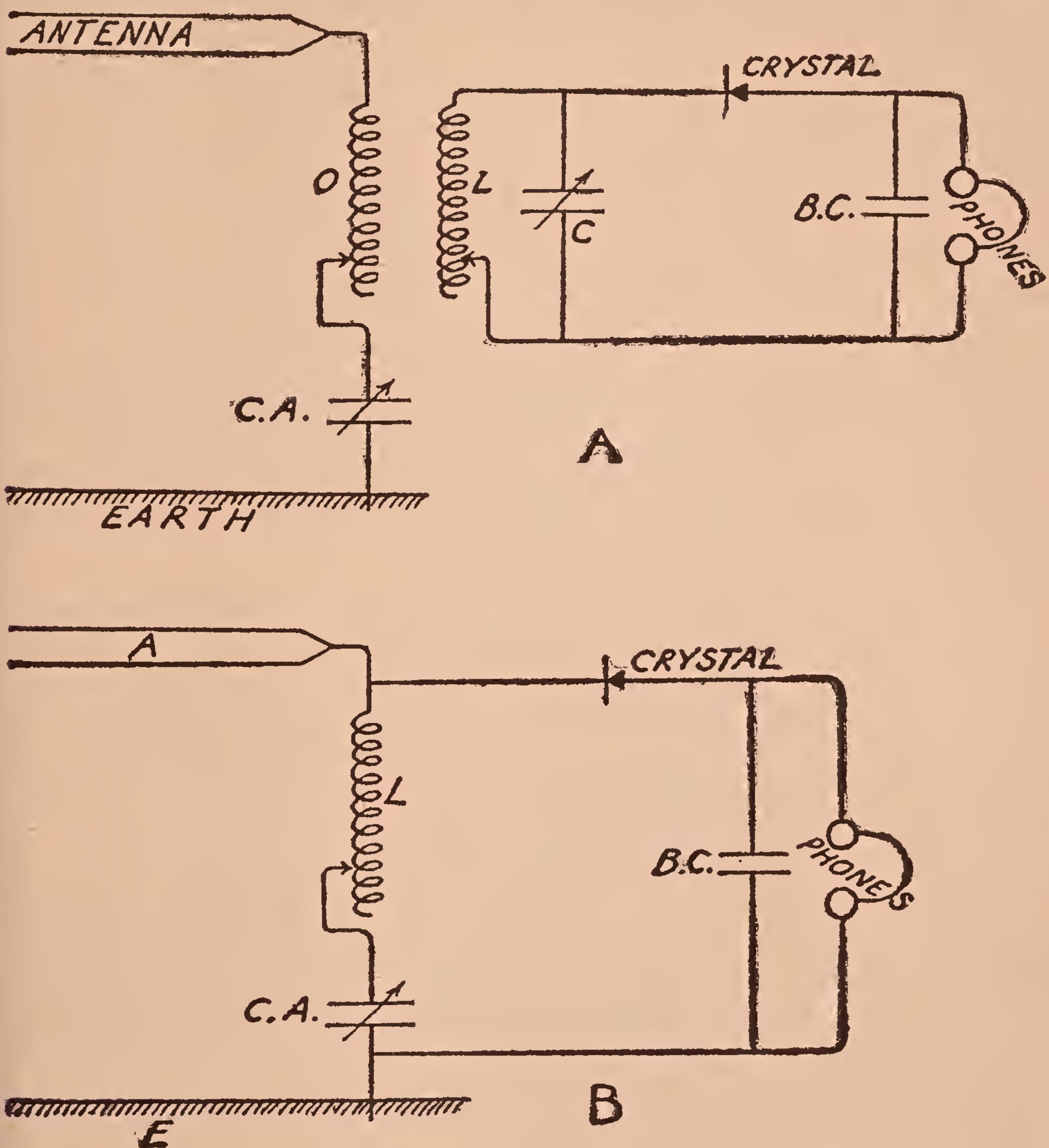

Fig. 102. Hook-ups of Simple Receivers.

Single-Circuit Tuners.—This name is not a correct one because all tuners have two circuits, the open and the closed oscillation circuits. Perhaps the single inductance suggested the name. While incorrect, this name will in all probability persist. The circuit is shown in Fig. 102B.

SELECTIVITY.—The Two-circuit tuner of Fig. 102A will tune sharper than a Single-circuit tuner like Fig. 102B.

The Two-circuit tuner has greater power of selecting the desired wave length but is apt to furnish weaker signals.

The Single-circuit tuner has less selectivity but gives louder signals.

TUNING.—The process of making a receiving circuit an electrical twin to the sending circuit is called tuning. These circuits may not look alike, they may not have the same kind of apparatus, but if the product of the microfarads of capacity and the microhenrys of inductance of the two circuits are equal, then considered as oscillation circuits they are identical. In two such circuits electrons put in motion will surge to and fro at the same frequency in each.

Perhaps the electrical explanations of why we can permit a wave length of 360 to enter a tuner and yet block off waves of 400 and 300 has not made you understand this process. If you will study the explanation you will understand it, but there is a way to help you to an understanding, and here it is:

ENTRANCE FOR 360 ONLY.—In Fig. 103 there is shown a snake trap. The entrance E is wide and inviting. There is a runway leading to the reception room. This trap is designed to catch one kind of snake only, the kind called by scientists 360. It is so arranged as to prevent other kinds from getting into the reception room.

The runway is made by two walls, just far enough apart that a 360 snake can make his wiggles as he makes his sinuous way into the runway.

Along the center line of the runway are a number of posts, and they are evenly spaced just as far apart as the runway is wide.

Along comes Mr. 360 Snake. Smelling an attractive

meal in the reception room he wiggles in the entrance and along the runway with perfect ease.

The width of the runway is wide enough for his graceful curves to be made in. The posts are just the right distance apart for the shape of his wiggles so that as in Fig. 103, he moves along without hindrance.

But when Mr. 400 Snake comes along, with his particular and unalterable shape and size of wiggle, he

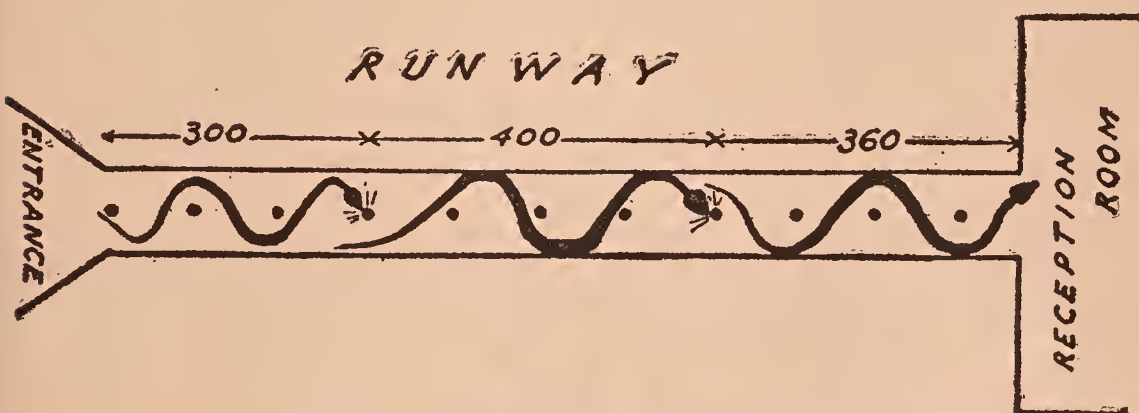

FIG. 103. "SNAKE TRAP."

has trouble. The runway is too narrow for his sinuosities. His body is uncomfortably bent and soon he slams his head against a post. If he could change his shape of wiggling he could get through but he is a 400 shaped snake and so he scrapes his sides and runs into posts until exhausted he quits.

Now saucy little Mr. 300 Snake comes along with his snappy little wiggles. The walls do not bother him, there's lots of room. Merrily he slithers along when bang goes his head into a post. Soon he quits. Those posts have been adjusted with a cleverness that is too much for any snake but a 360 kind.

This selective snake trap may not be placed on the market but it seems that it should work.

In radio reception the clever arrangement of inductance and capacity does keep out undesired frequencies.

Now we know how to absorb that frequency or as you would say that wave length which we desire, suppose we see what we are absorbing and by tuning transferring that and only that over to the rectifier.

How Speech and Music Come.—A Carrier Wave.—The transmitting station generates a carrier wave of a certain frequency, say 833,000 cycles per second. When they are ready to "send," their r. f. a. c. generator, which usually is a vacuum tube, is started and a carrier wave is placed in the ether. To help our minds understand we draw a picture. This picture in Fig. 104 is not a picture of the wave. It merely is a diagram that helps our minds to grasp the method of transmitting speech or music.

At C we represent the carrier wave of frequency 833,000, which takes 1/833000 of a second to make a cycle of values of current. As long as the station is transmitting or "on the air" as we say, this carrier wave is sent with absolutely regular frequency and equal amplitude. Equal amplitude would be expressed better by saying, "and constant energy." The distance marked C in the diagram represents 4 amperes of a. c. Hence the distance C represents the energy of the carrier wave.

The band plays into a telephone transmitter. Exactly as in the telephone in your home the current in the transmitter is changed by the transformer to an audio frequency a. c., with a frequency of any where from 200 to 3,000.

Modulation.—By a device called a modulator this audio frequency is made to alternately add and subtract energy from the carrier wave. We say that the amplitude (energy) of the carrier wave is changed and it has become a modulated (changed) carrier wave, as at B in Fig. 104.

Suppose the tune played by the band at a certain time has a frequency of 500. Then for periods of

1/500 of a second the carrier wave will undergo a series of changes in amplitude.

Let Fig. 104 help you to understand that the carrier wave goes on steadily at a frequency of 833,000, but that its amount of energy (amplitude) is varied at a frequency of 500.

This modulated carrier wave of radio frequency has its energy changed at an audio frequency.

Getting this last paragraph firmly in your head and a study of Fig. 104, not as a picture of a wave, for it

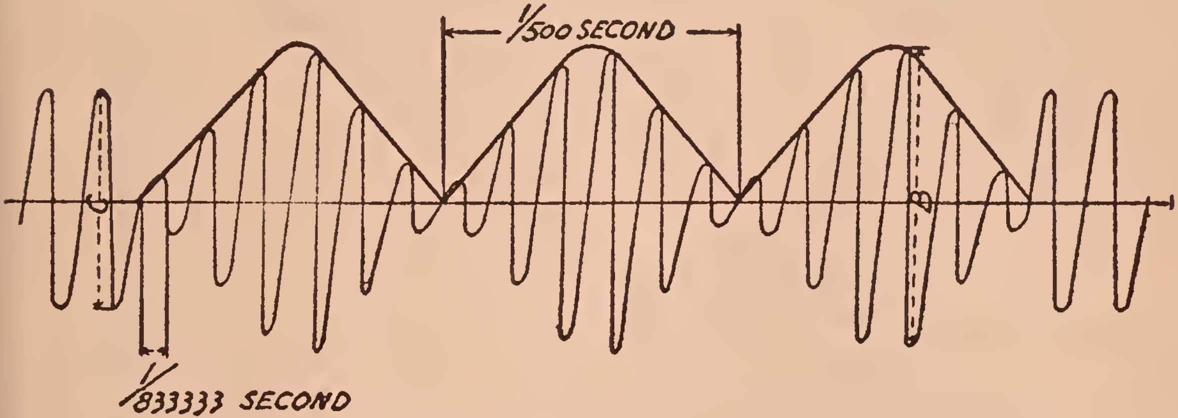

Fig. 104. A Modulated Carrier Wave.

is not that, but as a diagram to help you to understand, ought to make you understand how the speech and music come to us.

Reception by a Crystal.—In the first part of the book there was a discussion of materials and their internal structure. A mineral crystal such as galena is composed of electrons. When the energy of the oscillating electrons in the oscillation circuit arrives at the crystal, an alternate push and pull is exerted to set the electrons of the crystal in motion.

Such a crystal resists the push and pull unequally, so that there is a greater movement of the electrons in one direction than in the other. This action is more unequal at certain places. We then attach one circuit to the place of greatest inequality of action.

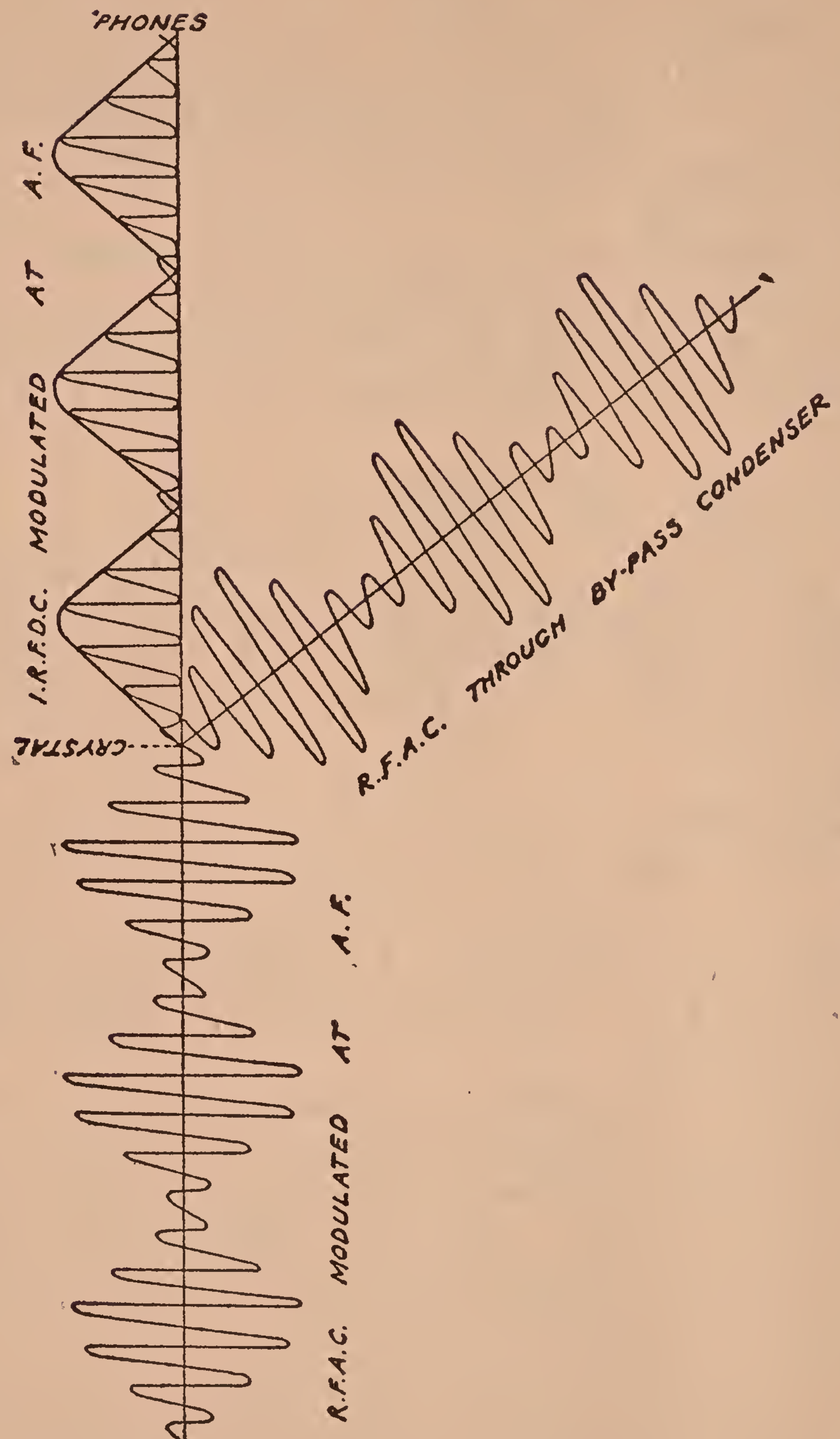

FIG. 105. ACTION OF A CRYSTAL.

Then the crystal rectifies. It changes the r. f. a. c. into an interrupted r. f. d. c. Since the r. f. a. c. was modulated (had its energy varied) at an audio frequency, the i. r. f. d. c. which passes through the crystal is also modulated at audio frequency.

The changes of the energy of the d. c. at a frequency of, say, 500 will cause the phones to emit a sound of that frequency, each group of energy acting as a short current of d. c.

But the crystal also allowed some r. f. a. c. to pass. The small condenser B. C. in Fig. 102, called a by-pass condenser, permits this to flow around the phones.

In Fig. 105 I have pictured in a diagram what happens when a crystal enables you to hear the sounds that originally varied the amplitude of the wave. In 106 I have given an illustration which will help you to understand the rectifying action of the crystal.

A series of narrow waves are moving in towards a breakwater C. Some source of energy out at A causes these waves to be higher and lower in groups, but does not alter the frequency of their arrival at C. The breakwater was built too low to stop the waves, but it does cut off the lower part of the wave motion and permits only the tops to pass. The crystal acts like this breakwater.

When these waves strike against a boat each little narrow wave will not rock the boat, but each group of waves will move it. Thus the motion of the boat is as if a wave motion like the black line of Fig. 106 came against it. The diaphragms of the phones act like the boat.

A Grain of Salt.—All illustrations from everyday life or from things easily within our ability to understand, which are intended to make clearer ideas that are rather difficult to understand, must not be taken too literally. Nor must they be taken as meaning that the electrical thing acts exactly like the snake trap or the

water waves. Use the illustrations to get your mind running along the proper line of thought and then try to master the electrical principle from the electrical explanation of it.

The Vacuum Tube.—This is a device that does not pass the received energy to the phones, as a crystal does, but instead uses this energy to open and close a valve, which controls a more powerful source of energy.

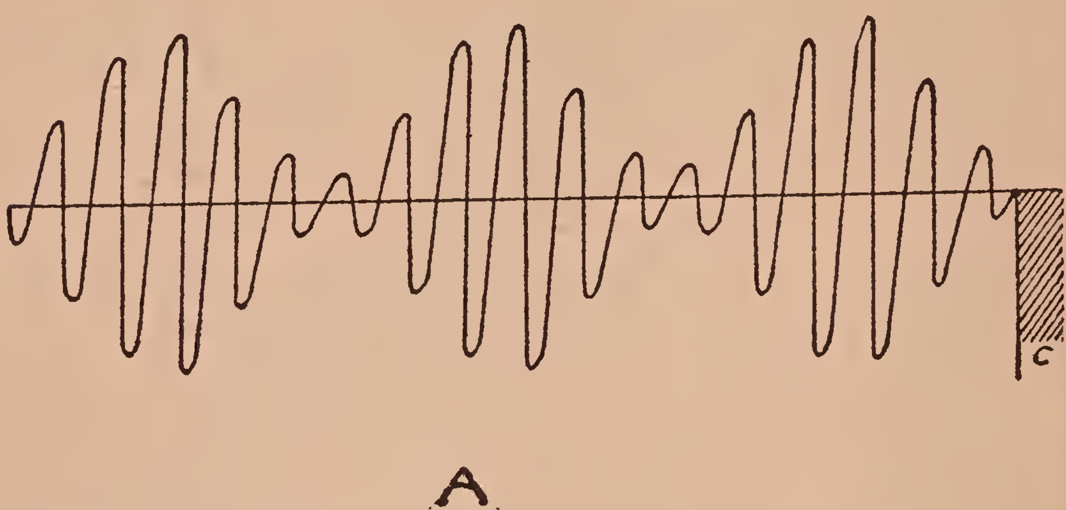

FIG. 106. EXPLAINING THE

For this reason vacuum tubes are often referred to as valves.

Thus the energy operating the phones may be many times greater than that absorbed by the antenna.

The vacuum tube is a glass bulb from which the air has been pumped out. Tubes in which the vacuum is almost perfect are called high vacuum or *hard* tubes. A tube in which a little gas has been inserted, after the air was all pumped out, is called a *soft* tube. The soft tube is more sensitive as a *detector* than a hard tube.

In the vacuum is a heated filament, a cold plate and a wire fence or gridiron of wire. They are called the filament, the plate and the grid.

THE FILAMENT.—An inspection of Fig. 107 will show an incomplete circuit starting from P through

the B battery, the phones and the filament F. The gap from F to P is in a vacuum. To bridge this gap and send electrons through the phones we might cause the filament to send out a stream of electrons with some force and arrange that the plate exert a strong pull on these electrons. This is exactly what we do.

The A battery heats the filament, for to get electrons out of any material we must make it very hot. When

B

Action of a Crystal.

fairly hot, atoms are boiled out of any metal and, like boiling water, it evaporates or boils away. When at a higher temperature electrons are boiled out also.

The hard dense metal tungsten is best suited to furnish a hot filament from which we can boil out a lot of electrons and yet be certain that as long as the filament is in a high vacuum it will last about 1000 hours before enough atoms are boiled off to destroy the filament.

A thin, narrow platinum ribbon covered with a thin coating of oxides requires a lower temperature and less power to boil out electrons.

To prevent these filaments from burning up they are, as I told you, sealed up in a vacuum. In the same vacuum tube with the filament is a cold metal plate to catch the electrons boiled out of the hot filament.

Electrons flow from a place of negative potential over to one of positive potential, hence if the hot filament is charged negatively then the high temperature boils electrons off and the negative condition urges them away.

The A Battery is not a part of the oscillation circuit. It is a battery of the proper voltage and ampere-hour capacity to heat the filament. It is connected to the

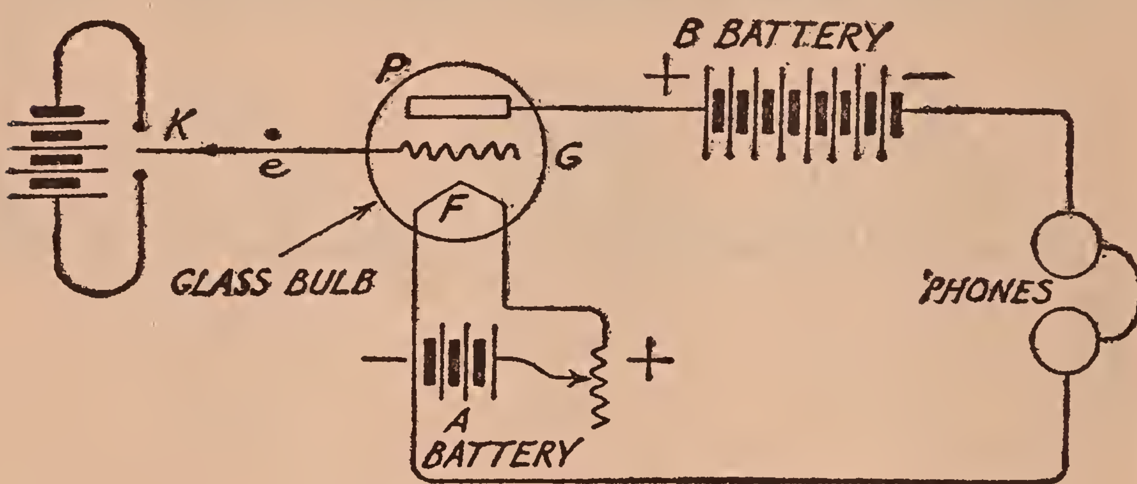

Fig. 107. Action of a Vacuum Tube.

circuit so as to give the filament a negative charge. A storage battery or dry cells are used according to the type of vacuum tube used. A rheostat is used to control the amount of current in the filament.

The B Battery is usually composed of dry cells. It furnishes from 16 to 45 volts pressure. Its purpose is to give the plate a strong positive charge and cause it to pull over to the plate all the electrons that the filament can boil off.

Following the circuit in Fig. 107 from the negative terminal around to the filament you will perceive that, while the + end of the B battery makes the plate attract electrons, the — end of the battery is sending a stream of electrons to the filament for it to boil off.

Now you see how a stream of electrons may flow from F to P, through the phones back to F. And notice that this is a one direction flow and so is d. c.

THE PLATE.—This cold plate of molybdenum is made large enough so that the electrons emitted by the filament will be sure to land on the plate. Its work has been described in the preceding paragraph.

THE GRID.—This is a device that will make the electrons stop and start. It consists of a network of wires and is placed between the filament F and the plate P.

The grid is nearer the filament than the plate is and so exerts a greater influence on it. If a switch K enables first the positive and then the negative end of the battery D to be connected to the grid G, then this is what happens.

When the grid is positive it exerts a strong pull on the electrons from the filament F. As they rush towards the grid, which you remember is a network of wires, very few hit the grid but pass through its meshes and feeling the pull of the plate go on to it.

But when the grid is made negative it says to the electrons boiling off of the filament, "Stop. Go back." Because the grid is nearer the filament than the plate is, the repulsion of the grid may be weaker than the pull of the plate, and yet its action predominates and so it can stop the electrons.

Thus the grid determines whether the electrons may rush from F to P or not. When they are permitted to flow the B battery furnishes the power to make them move.

Reception of Signals.—Signals meaning voice, music, telegraphy or any kind of modulation (change of energy) of the carrier wave.

Suppose the grid G of Fig. 107 to be connected to the antenna circuit or coupled to it by an oscillation transformer. In either case there will be set up in the wire leading to the grid oscillations of electrons at radio frequency.

Consider the electron *e*. The first part of an oscillation in that wire sends the electron into the grid. The

grid becomes negative and says, "Stop," to the electron trying to go from F to P. Then there is no current in the phones. The second part of the oscillation pulls the electrons out of the grid. The grid becomes positive and says, "Come," to the electrons trying to go from F to P. Then there is current in the phones.

There are, of course, intermediate actions according to the amount of energy in the modulated carrier wave that arrives at the antenna. Sometimes the grid speaks softly, sometimes loudly; sometimes drawls its commands and sometimes is very peremptory.

The grid acts as a regulator of the F to P electron flow and its action is controlled by the distant signals, perhaps 1000 miles away. It regulates the current from the B battery, and since this is d. c. the vacuum tube acts as a rectifier, changing r. f. a. c. into i. r. f. d. c.

Precisely as in the explanation of a crystal rectifier, the phones repeat to you the sound of the distant signal.

THE DETECTOR.—To call a vacuum tube or a crystal a detector is certainly misnaming it. They are not detectives, merely rectifiers or changers, and in the case of the vacuum tube, an amplifier.

AN ACTUAL SET.—In Fig. 108 is given the hook-up of a receiving set using a vacuum tube.

The oscillations which are set up in the closed oscillation circuit pass through L, F, G and back to L. The direct current interrupted at radio frequency carrying energy changes at audible frequency passes through the circuit P, phones F, back to P.

Should any a. c. leak from the grid to the plate a by-pass condenser would be needed to shunt this a. c. around the phones. The two wires in the telephone cord being close together and from 3 to 6 feet long form such a condenser. An additional by-pass condenser is rarely needed.

GRID CONDENSER AND GRID LEAK.—Many vacuum tubes will not operate satisfactorily unless a small con-

denser is placed in the wire to the grid and unless this condenser is shunted by a very high resistance called a grid leak.

The grid condenser, by trapping electrons between it and the end of the grid, makes the grid very negative, when it is negative. This makes the grid shout "Stop." The more completely the grid stops and allows a passage to the electrons, the greater the variation in the plate circuit current. It is the variations of the d. c. current that operate the phones.

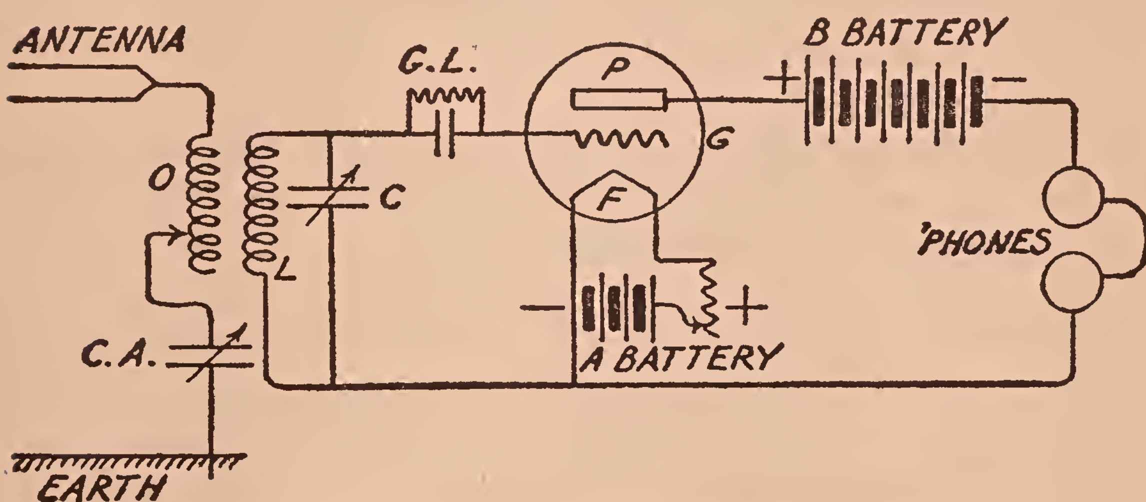

FIG. 108. RECEPTION BY A VACUUM TUBE.

But this condenser will ultimately trap too many electrons, making the grid negative all the time. This will block the tube so that there is no plate circuit current nor could there be any.

The Grid Leak.—A very high resistance, G L of Fig. 108, will allow these trapped electrons to leak away at a slow rate.

If the value of grid condenser, about 0.0002 microfarads, and the grid leak, about a million ohms, are properly balanced, we get the advantages of the grid condenser with practically none of its possible bad effects.

THE PLATE CIRCUIT.—We have talked a lot about tuning the open and closed oscillation circuits, but did

not mention the plate circuit. This circuit needs adjusting, if we are to get the best results from a receiving set.

When the vacuum tube is in operation it acts like a generator of interrupted d. c. It is a fact that if a generator and a receiver of energy are in a simple series circuit, that the greatest possible current will flow if the resistances of the generator and receiver are equal.

For this reason we want phones of high impedance to match the high impedance of the tube. It is a queer statement but a true one, that phones of high impedance are a necessity to force the tube to send a large current to the phones.

Non-Regenerative Receiving.—All the methods of reception described so far fall under this heading.

Regenerative Receiving.—There are two methods of greatly increasing the strength of the signals as heard in the phones. One is by *tuned plate circuits* and the other by a transformer action called a *feed back.*

TUNED PLATE CIRCUITS.—It will be sufficient now to remind you that an interrupted d. c. must build up the magnetic fields of its circuit after every interruption. It therefore acts a little like a. c.

When a variometer is placed in the plate circuit and properly adjusted there is a decided increase in the signal strength.

The Variometer.—A variable inductance is a coil of wire so mounted that another coil of wire may revolve within it. The coils are connected in series. There is capacity between the turns of the coils and between the two coils. There is inductance in the coils, which is most when they have their axes parallel and least when they are at right angles.

By the rotation of the inner coil the capacity and inductance are so altered as to reduce the impedance to a. c. to almost zero.

THE FEED BACK.—*The Tickler.*—Another method

of feed-back or regeneration is by use of a coil in the plate circuit arranged so as to be coupled to the closed oscillation circuit. Fig. 109 shows how this may be done. This is a diagram of what is called incorrectly, but yet by almost everyone, a *single circuit* tuner.

The coil T in the plate circuit is called a *tickler.* It is pivoted so that it may be rotated, thus increasing or decreasing the amount of feed-back.

The mutual induction between the tickler T and the coil L which feeds the electrons to the grid is such that when L is sending electrons to the grid, T also pushes

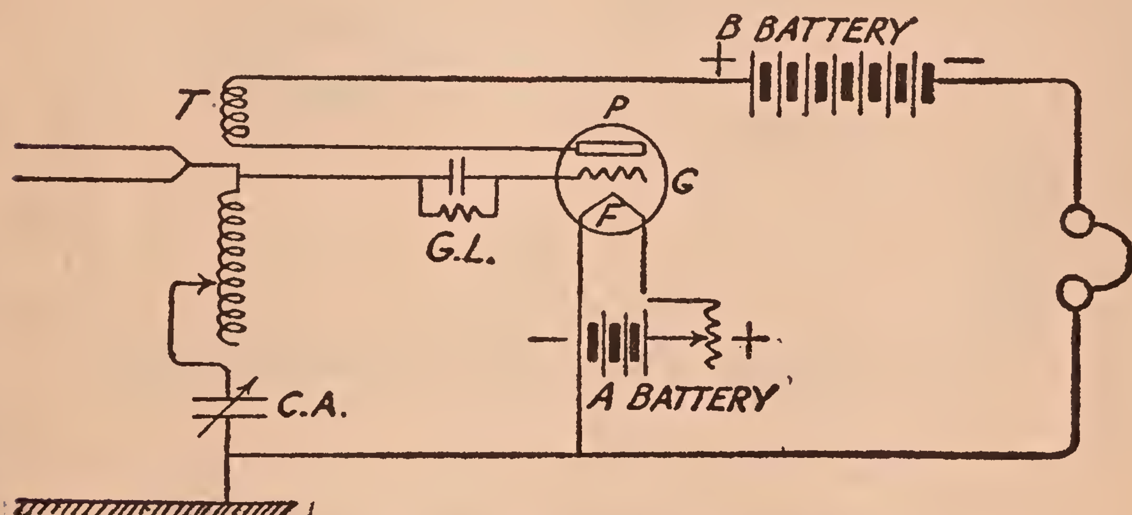

FIG. 109. A REGENERATIVE CIRCUIT.

electrons through L towards the grid, thus resulting in a greatly increased charge in the grid. This in turn increases the plate current. But this increased current passes through the tickler coil T and again acts on the coil L. This building up, or feed back or regenerative action, goes on until the tube is passing all the filament to plate electrons that it possibly can.

This regenerative action greatly increases the strength of the signal as heard through the phones.

Amplification.—The sets using vacuum tubes which have been described might be called a combination of a tuner, a rectifier and amplifier. But when we speak of amplification we usually mean much more

amplification than such a combination gives. There are two methods. Their names are audio frequency and radio frequency amplification. Each amplification obtained by passing the energy through a tube is called a *step* or *stage* of amplification.

AUDIO AMPLIFICATION.—From any of the sets shown in Figs. 108 and 109 remove the phones and put a step-up transformer in its place. Connect the secondary of this transformer to a vacuum tube precisely as if the secondary of the transformer were the coil L

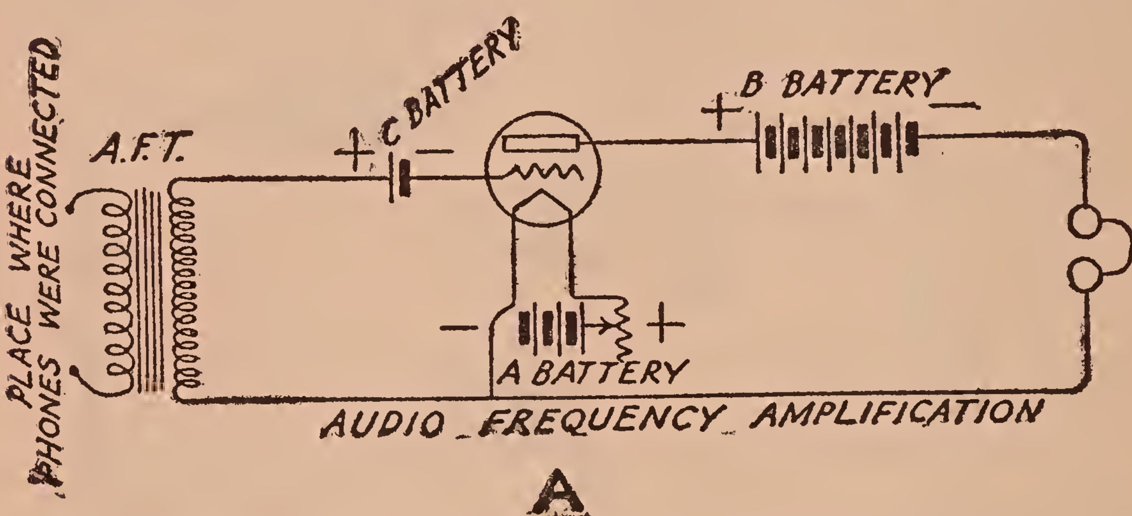

FIG. 110. AMPLIFICATION AT AUDIO FREQUENCY.

of a closed oscillation circuit. You will then have a hook-up as in Fig. 110 added to the place where the phones were.

The stream of electrons set in motion by the audio frequency transformer A.F.T. of Fig. 110 is a. c. The interrupted direct current in the primary of any transformer or induction coil causes an alternating current in the secondary.

The oscillations of the electrons from the secondary of the audio frequency transformer are impressed on the grid and thus control the power from the B battery. The B battery of a detector tube furnishes from 18 to 45 volts, but when used in amplification circuits the B battery furnishes from 45 to 90 volts.

The grid circuit in such an audio frequency amplifier does not need tuning because although but one frequency is imposed upon the currents at a time, in the course of one second all the frequencies from 100 to 3000 are sent into the grid circuit. Tuning would damp out some of them.

No transformer can have the same impedance to all frequencies. So some of the audio frequencies are weakened, thus distorting the sound which we hear.

Using an audio frequency transformer suited to the vacuum tube used and to the *stage* of amplification in combination with phones of proper impedance we will produce the greatest possible signal strength in the phones.

A vacuum tube with a very high vacuum is best suited for amplifier circuits, for you can use a high plate voltage with such tubes. Any ions of gas in the tube, as argon, nitrogen or helium, would with high B battery voltage conduct electrons from filament to grid. This would rob the filament to plate stream of electrons, with the result of weakened signal strength in the phones.

For the very high amplification to operate a loud speaker, the phones in Fig. 110 may be removed and another step of audio amplification added.

Since the distortion of each step is forwarded to the next step and amplified, two steps seems to be the practical limit.

All the noises of chemical action in the B battery, any thermal electrical effects from unequal heating of the joints and connections in the set make noises, and these are amplified. This also makes more than two steps unwise.

C Battery.—We do not use a grid condenser and a grid leak in amplification circuits. A leak that would operate properly for a frequency of 1000 would leak

too fast for 200 cycles a second and not fast enough for 2000 cycles a second.

Since in a audio amplification grid circuit we are handling frequencies from 100 to 3000 the grid condenser and grid leak will not do.

A result similar to the grid condenser is performed by a voltage of 3 volts applied in the grid circuit. This is called the C battery and is said to give "the proper negative potential to the grid."

Amplifiers that you purchase do not use a cell or

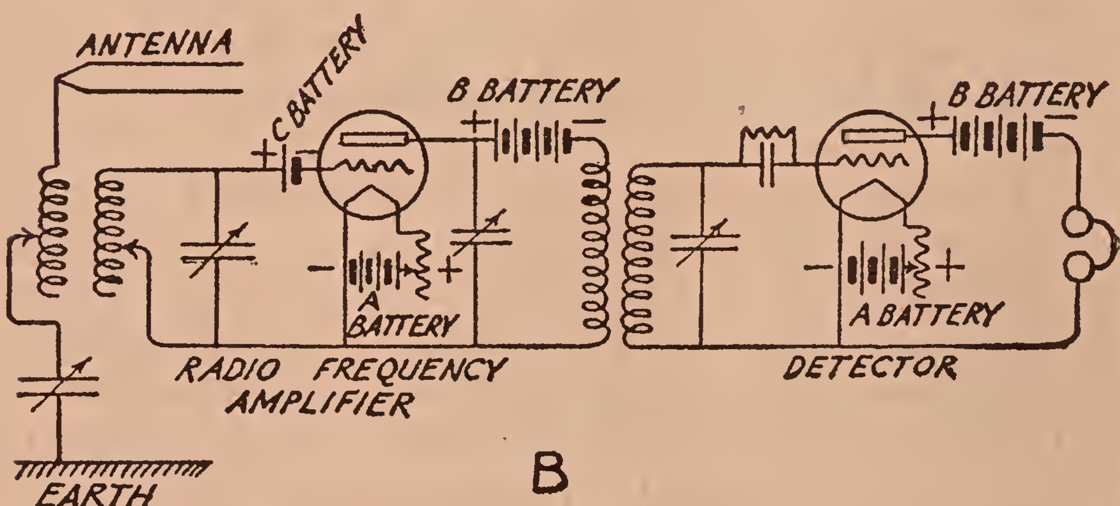

Fig. 111. Amplification at Radio Frequency.

cells to furnish the C battery voltage. In them the principle shown in the reducer in Fig. 6 is used.

A small portion of the *drop* through the filament rheostat is used instead of a cell. Whenever a difference of pressure exists, that *drop*, as we call it, will act as a cell and furnish voltage.

Radio Frequency Amplification.—This means amplification of the incoming energy at radio frequency. There are many carrier waves in the ether, and we wish to keep out all but the desired one. For this reason the absorbing circuit and the one to which the energy is transferred should be tuned.

The incoming signals affect the grid of a vacuum tube and it operates in the same manner as an audio

frequency amplifier except that the energy handled is at radio frequency. The B battery should furnish from 90 to 110 volts to a *hard* vacuum tube.

Less energy will be used up if the impedance of the plate circuit is made almost zero by proper tuning.

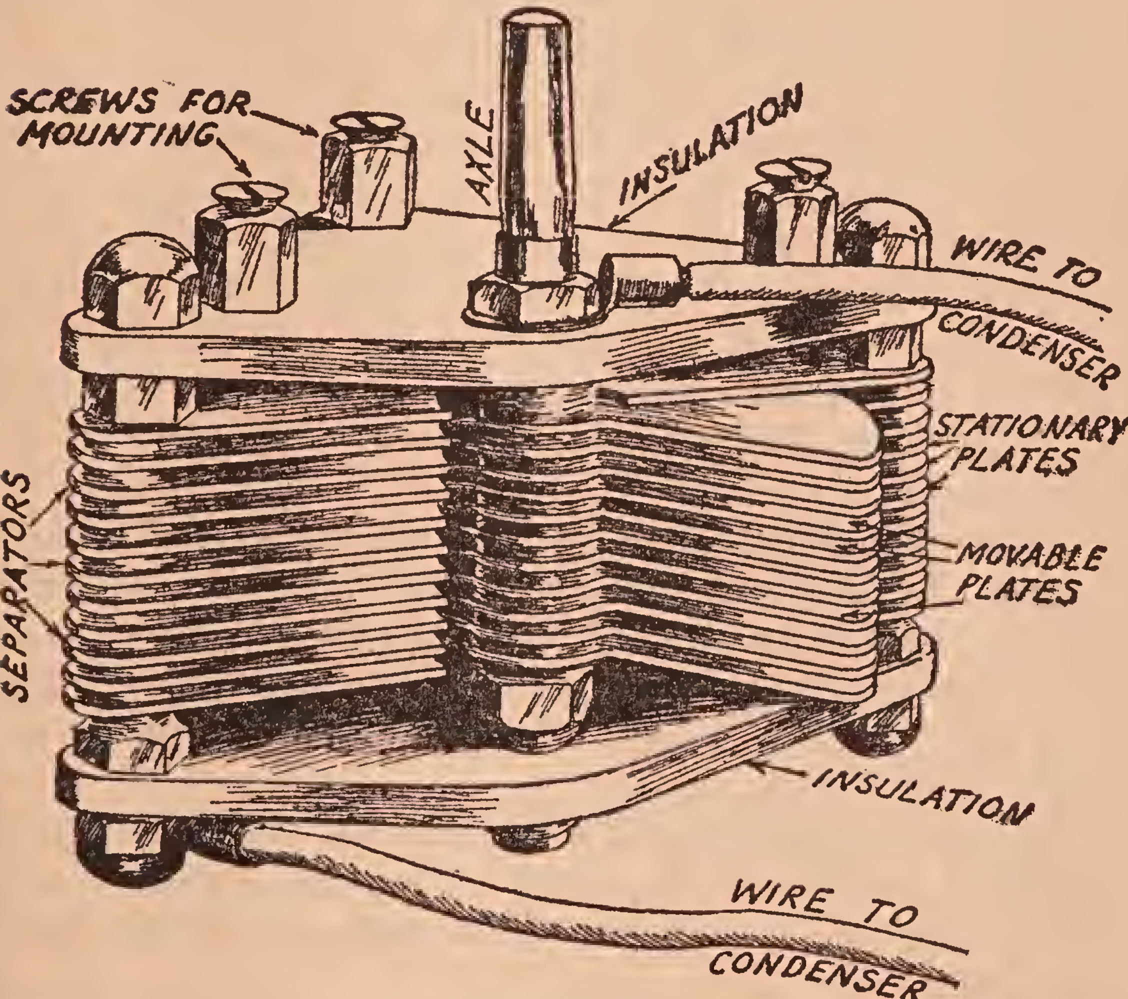

FIG. 112. VARIABLE CONDENSER WITH AIR DIELECTRIC.

The output of a radio frequency amplifying set may be transferred in two ways, to a detector tube circuit where it is changed to d. c. at audio frequency. An oscillation transformer with no step-up in voltage may be used or one with a step-up in the voltage.

Transformers for audio frequency work are not suitable for the high frequencies of the carrier waves. For

radio frequency amplification only those transformers designed for this special purpose and for a particular range of wave lengths should be used. See Fig. 111.

Variable Condensers.—The small fixed capacity condensers may be made of tinfoil or copper foil with mica as the dielectric. The condensers of variable capacity used for tuning are constructed with aluminum plates and use air as the dielectric.

Rotation of the movable plates in between the stationary plates increases the capacity and tunes the circuit, of which the condenser is a part, to longer wave lengths. Fig. 112 shows such a variable condenser.

Building Receiving Sets.—Start with a crystal set. Send ten cents in silver to the Commissioner of Public Documents, Washington, D. C., asking for a copy of the Bulletin No. 120 of the Bureau of Standards.

When you want a receiver that will respond to weaker signals, build a vacuum tube set. Go to a reputable dealer and talk to him; let him see that you know what you have read in this book. He will then know that he can talk radio to you, rather than about knobs and mahogany boxes.

Buy the materials to build the set the hook-up of which is shown in Fig. 109. He will probably wish to sell you the coils L and T in one unit, which is the best plan.

Until you are experienced beware of circuits named after some man. Beware of supers, reflexes, variable grid leaks. Some day you will handle them with ease, but at the beginning of your experiments they will make your set very complicated and perhaps you will be unable to make it work.

Reading Radio Hook-ups.—The wiring diagrams use symbols which must be translated into English before you know what to buy and how to wire them. Fig. 113 will enable you to translate diagrams.

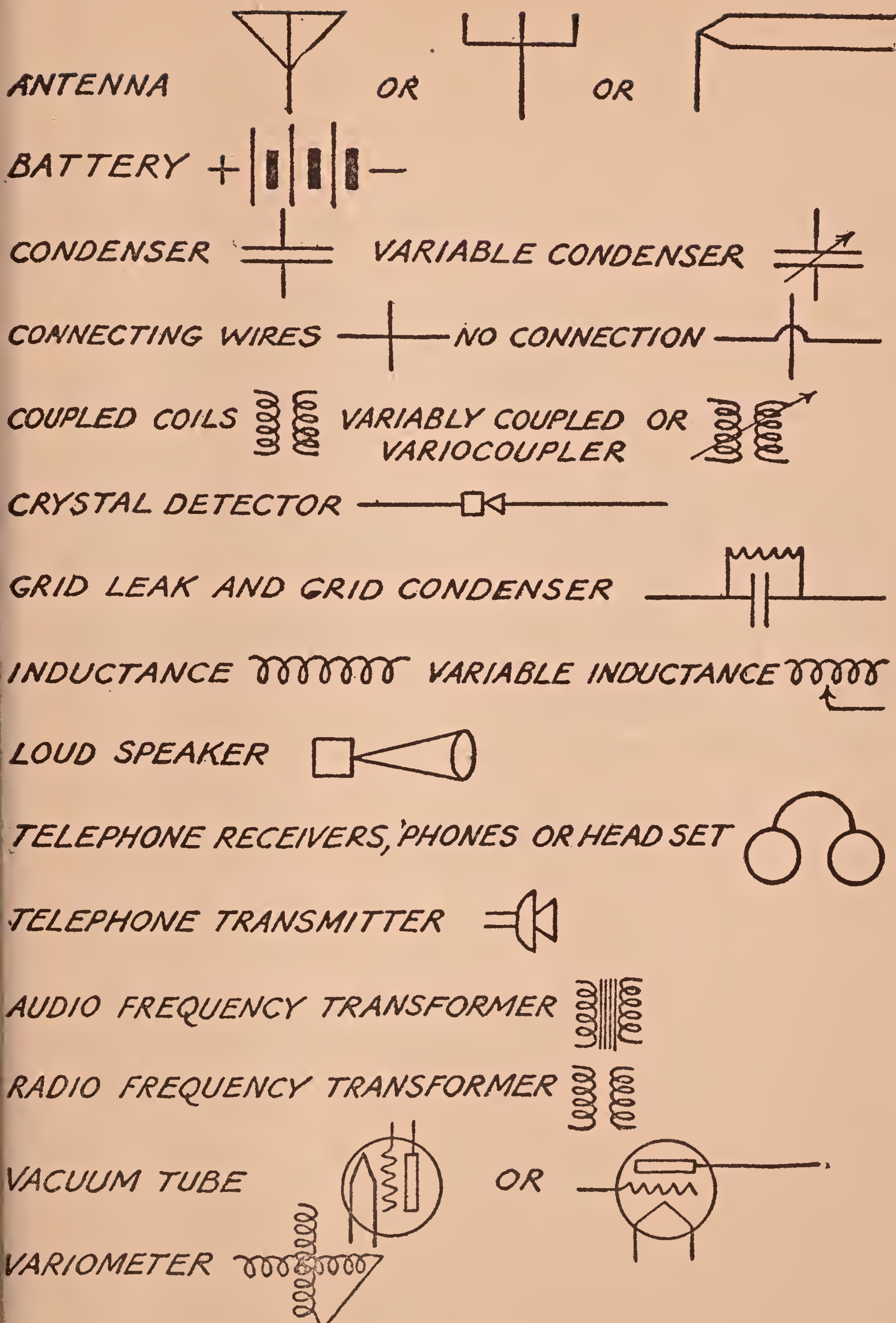

Fig. 113. Standard Symbols Used in Radio Wiring Diagrams.

SIGNING OFF

This is station **S. A. S.** *International Writo-phone Station of E. P. Dutton & Company, at New York, N. Y., U. S. A.*

The book you have just read was broadcast from our author's laboratory by the publishing establishment of E. P. Dutton & Company.

Please stand by until our next book.

GOOD NIGHT.

GLOSSARY

A Battery.—A battery furnishing current for the filament of a vacuum tube.

a. c.—An abbreviation for alternating current.

Alpha particles.—When two electrons and four protons are thrown out, in a compact group, from a nucleus, we call the group an alpha particle.

Amalgam.—An alloy or mixture of metals, one of which is mercury. Iron does not form an amalgam.

Ampere-hour.—One ampere for one hour. Two amperes for half an hour, or any such combination. The unit of work that a storage battery will do.

Analogy.—A resemblance between things otherwise quite different. Like the flow of water and electric current.

Antenna.—A long straight wire or wires collecting or radiating electrical energy.

Atom.—A nucleus surrounded by half as many electrons as there are protons in the nucleus. There being an equal number of electrons and protons in the atom it is neutral, that is, electrically unchanged.

Armature.—A core of iron surrounded by coils of insulated wire, revolving near the poles of a magnet, in a dynamo. Also a movable piece of soft iron placed in front of a pole piece of a magnet, so that it can be attracted by the magnet.

Battery.—A group of cells considered as a unit. Usually only two wires lead from a battery to the work.

B Battery.—A battery, usually of dry cells, furnishing from 16½ up to 112½ volts for the plate circuit of a vacuum tube.

B. C. L.—A broadcast listener who is not interested in intercommunication by code. B. C. L. frequently know nothing about radio nor care about it, being merely knob turners.

Beta particles.—The electrons which are shot out one by one from the nucleus of some atoms. Electrons given up or taken from the outer swarm of electrons of an atom are not called beta particles.

Blow.—Slang word used for melt. We say that a fuse blows.

Bore.—The bore of a tube is the hole inside of it.

Brass Pounder.—A telegrapher.

B. T. U.—British Thermal Unit. The amount of energy in the form of heat that will raise 1 pound of water 1 degree Fahrenheit.

B. X.—Two wires of size No. 14 or larger, insulated with rubber and cotton, then enclosed in a flexible metal armor.

Calorie.—The amount of energy in the form of heat that will raise 1 gram of water 1 degree Centigrade.

Carrier wave.—A continuous wave sent out as long as the station is transmitting. This wave of very high frequency cannot cause voice or music at the receiving station, but acts as if it carried certain **modulations.** These are the cause of the voice or music.

Cell.—A single unit of a battery.

Condenser.—A device for accumulating electrons by their mutual actions from one conducting plate to another, through an insulator called a **dielectric.** Condensers obstruct d. c. but allow a. c. to pass.

Constant.—Steady. Not changing. A special number. We speak of the **constants** of a circuit. We say that 746 watts are equivalent to a horsepower. 746 is a constant.

Combined resistance.—The effective resistance of any combination of resistances. Usually refers to the effective resistance of several resistances in parallel.

Cord.—When used in the phrase "lamp cord" means a pair of flexible copper wires properly insulated and bound into one cord by cotton or silk threads.

Current.—A flow of electrons through a definite path. The direction of the current is, by agreement of scientists, said to be in the opposite direction to that in which the electrons are moving. We say the current flows from the + to the —, while we know that the electrons flow from the — to the +. See Fig. 41.

Cycles.—Repetitions of anything in exactly the same way. One cycle is one round trip back to the start and all ready to do it again.

Damped.—Means diminished.

d. c.—An abbreviation for direct current.

Deflection.—When the pointer of a galvanometer or other meter moves over to a reading and stays there, we call this action "a deflection."

Dielectric.—An insulator specially adapted to be used as the insulator between the plates of a condenser, for it opposes the passage of electrons yet allows the force caused by electrons to pass through it.

Dowel rod.—A cylindrical rod of hard wood. May be obtained in many sizes of diameters.

Electrode.—That part of a solid conductor thrust into a liquid, a gas or a vacuum is called an electrode. The electrode is usually a plate or rod of some different material connected to the copper conductors.

Electrolyte.—A liquid conductor whose atoms have separated into groups carrying electrical charges. These groups are called ions.

Electromotive force.—The pressure developed to push electrons. An electron motive force.

Electron.—A tiny speck of negative electricity. Electrons, protons and energy make up the materials of our world.

Emanation.—When alpha particles are shot out of radium, a product is formed by these alpha particles called radium emanation.

Energy.—The motive power that makes things move and keeps them moving. Energy added to electricity makes the substances of our world.

Erg.—About one thousandth part of the work needed to lift one gram up from the earth, vertically, for one centimeter. Two grams moving at a speed of one centimeter a second can do one erg of work.

Ether.—An imaginary substance which, if it does exist, fills all the spaces where there is no material.

Fan.—A B. C. L. who follows radio closely.

F. b. o. m.—Fine business old man. The radio amateur's way of expressing approval.

Feeder.—A conductor carrying current to and from the subsidiary or branch circuits. Apparatus is not connected to feeders.

Filament.—(Of a lamp.) A thin wire.

Flux.—1. A material which cleans metal, so that solder may adhere. 2. The flux or flow of magnetism through a magnetized space.

Frequency.—The number of vibrations or oscillations in one second. Divide the speed by the wave length to obtain the frequency.

Fuse.—A wire, bar or strip of lead or some readily melting alloy which melts (blows) when a current passes through it stronger than that for which it was designed to carry.

Ground.—1. A term applied to the earth as a conductor. 2. An accidental or undesired connection between a circuit, line or apparatus and the earth.

Ham.—Originally meant a "brass pounder" with a fist like a ham. Now applied to persons regularly engaged in wireless telegraphy for the love of the work. The "hams" sent and received 160,000 messages in March, 1923.

Hook-up.—A wiring diagram showing the electrical connections and relative positions of apparatus.

Hydrometer.—An instrument for determining the specific gravity (density) of liquids. The lighter the liquid the deeper the hydrometer sinks.

Insulators.—Substances which conduct so poorly that we use them to confine electricity along certain paths or in certain places. At high pressures insulators conduct slightly.

i. r. f. d. c.—See after r. f. a. c.

Ion.—An atom, molecule or radical which, having gained or lost electrons, has become electrically charged.

Isotope.—A substance which to a chemist is the same as one or more other substances, but to an electrical investigator is different from them. Isotopes differ only in their nuclei.

Jack.—A device consisting of one or more strips of metal held in insulation. It may close or open circuits or do both when the plug is inserted.

Joint resistance.—The same as combined resistance.

Juice.—A slang word for current or flow of electrons.

Kick.—(Of a galvanometer.) When the pointer moves over to a reading and immediately falls back to zero, we call it a kick. The number to which it "kicks" we call the reading.

Kinetic energy.—The work that electricity can do because it is in motion.

Kink.—(In a wire.) See Fig. 7.

Laminated.—Consisting of thin layers.

Lay-out.—A paper pattern on which all the apparatus is arranged in full size and actual shapes. It shows the wiring according to the hook-up and the holes to be drilled to mount the apparatus.

Lead-in.—A wire or wires from the antenna to the receiving set.

Loud speaker.—A specially designed telephone receiver combined with a horn.

Lug.—A piece of metal to be soldered to a wire and its other end clamped under a binding post or switch terminal. Used to make a strong mechanical and good electrical connection.

Mass.—Electricity has, besides its electrical qualities, another separate and distinctly different property called mass. Mass is that which makes bodies hard to start and hard to stop.

Modulations.—Changes in the amount of energy in a carrier wave.

Molecule.—A group of atoms joined by electrical forces. In it are an equal number of protons and electrons, hence electrically it is neutral or uncharged.

Multiple.—Older name for "parallel."

Nucleus.—Some protons and half as many electrons in a compact body at the center of an atom.

On.—A slang term for "connected to" or "in the circuit with."

Open circuit.—A break or very high resistance in a circuit, making it useless for the work required of it.

Orbit.—The path along which a body moves in getting back to the place from which it started.

Oscillate.—Means vibrate.

Parallel.—Indicates that the current splits and a different part of it passes through all the parts of the circuit that are in parallel.

Permeability.—The relative ease with which magnetism passes through a material.

Plug.—A device to push against the strips of a jack and thus move them. This causes them to make the proper contacts.

Permanent magnet.—A magnetized piece of hard steel which, due to its retentivity, will continue to be a magnet for a long time.

Phenomenon.—(Plural phenomena.) Some action that you can see, feel, hear or observe in some way. Not used in science with the meaning of unusual or extraordinary.

Power-house.—A name given to a place where electrical power is generated.

Primary cell.—A cell which, like a tobacco pipe, must be refilled with the same chemicals that were originally in it.

Proton.—The tiny speck of positive electricity.

Quantum.—(Plural quanta.) The tiny amount of energy radiated at one time. Energy is not radiated continuously but in quanta. The size of a quantum changes with the frequency of the oscillations of the electrons radiating the energy.

Radiation.—Energy travelling through space by itself. Energy often travels on substances. It is also radiated from substances and is then called radiation.

Radical.—A group of atoms which in ordinary chemical actions does not separate. Neutral or unchanged radicals can only exist when combined with something. Radicals not in combination are charged and are called ions.

Radioactive.—The nuclei of some substances explode, throwing off protons and electrons. In this way radioactive substances change to new substances.

Reads.—Slang for "indicates."

Rectifies.—Chances a. c. to d. c.

Resistance coil.—A long wire coiled up to occupy less space, which resists the passage of electrons.

Resin.—The sticky part of the sap, or made by the sap of trees, which hardens on exposure to air. Rosin is resin from the long leaf pine tree.

Resonance.—See Tuned circuits.

Retentivity.—When a material keeps some magnetism after the magnetizing force is removed.

r. f. a. c.—An alternating current, the number of cycles per second of its electrons being very high.

i. r. f. d. c.—A direct current interrupted at radio (high) frequency.

Rheostat.—A variable resistance.

Rosin.—See Resin. Used as a flux in soldering. Also to make sealing wax.

Series.—Indicates that the same current passes through all the parts of the circuit that are in series.

Set-up.—The actual apparatus arranged and electrically connected according to the hook-up.

Shellac.—Made by insects. Looks like a resin. Dissolved in alcohol it makes a quick drying, insulating varnish.

Shunt.—A shunt on an electrical circuit is like a side track on a railway. It carries the electrons around a certain place in the main line.

Solenoid.—A coil of wire carrying current. An air core electromagnet.

Static.—1. An electrical charge which stays where it was formed. A few electrons at very high pressure. 2. Atmospheric or ground charges which affect a radio receiving set.

Storage cell.—A cell in which the original chemical may be restored by passing a current of electricity through it.

Specific.—Means special.

Takes a current.—Slang for "permits a current to pass."

Temporary magnet.—A magnetized piece of soft iron which, due to its low retentivity, will become demagnetized as soon as it is removed from the magnetic field.

Tension.—Used in phrases "high tension," "low tension," it means voltage.

Time constant.—The fraction of a second which an electron needs to make one oscillation in a particular circuit is called the time constant of that circuit.

Transformer.—A device operated by magnetism which, without any electrical connection between the two circuits, transfers alternating current power from one to the other. It usually changes the voltage.

Tuned circuits.—When the combination of inductance and capacity in a circuit is adjusted to offer the least possible resistance to a certain frequency, we say the circuit is tuned. When two circuits are tuned to the same frequency we call them tuned circuits. They are also in resonance.

Turbine.—A modern and efficient form of water wheel. Also a similar device using steam at the motive power.

Vacuum.—A space from which all the known materials have been removed. As far as we can determine by all sorts of tests, a vacuum is empty.

Voltage.—The pressure exerted by a cell, dynamo, etc., on a stream of electrons.

INDEX